AN ABSTRACT OF THE THESIS OF

Glen E. Murphy for the degree of Doctor of Philosophy in Forest Engineering presented on April 7, 1987.

Title: An Economic Analysis Of Final Log Manufacturing Locations In The Steep Terrain Radiata Pine Plantations Of New Zealand.

Abstract approved : Eldon D. Olsen

Eldon D. Olsen

Over the next quarter century there will be about an eight-fold increase in the volume of wood harvested annually from New Zealand's steep terrain radiata pine plantations. With the move to steeper terrain it is expected that there will be a trend towards considerably smaller landings. With smaller landings final log manufacture could have to take place at alternative locations to the large landings normally used. The locations examined in this thesis were: at the stump, at a landing, and at a central processing yard. Comparisons were made on the basis of value recovery, harvesting productivity and costs, and land taken out of production by landings.

A field trial indicated that value recovery at the landing was better than at the stump but the magnitude of difference was dependent on individual log manufacturers.

Better value recovery on the landing was generally due to more logs meeting specification and more accurate length measurements.

Radiata pine stems are too long to be hauled to a central processing yard without some initial cuts being made at the stump. Initial cuts preempt future log manufacturing decisions. An analysis of fixed long length patterns indicated that about 5% of possible value would be foregone by these preemptive cuts.

To analyse the effect of alternative log manufacturing locations on harvesting productivity and costs a stump-to-milldoor simulation model was constructed. Tree-length logging to large landings was the most productive and least costly alternative, the stump was the second best alternative, and the central processing yard was the most expensive and least preferred alternative.

In an overall economic analysis it was concluded that where possible large landings and yarders should continue to be used. Where it is not possible to use large landings, final log manufacturing should be carried out at the stump, provided log manufacturers have hand-held computers to assist them in decision making so that value recovery is kept as high as possible.

An Economic Analysis Of Final Log Manufacturing Locations In The Steep Terrain Radiata Pine Plantations Of New Zealand

by

Glen E. Murphy

A THESIS

Submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Completed April 7, 1987
Commencement June 1987

APPROVED:

Eldon D. Olsen

Associate Professor of Forest Engineering in charge of major.

William A. Atkinson

Head of Department of Forest Engineering.

Dean of Graduate School.

Date thesis is presented: April 7, 1987.

Typed by researcher for : Glen E. Murphy.

ACKNOWLEDGEMENTS

The research reported in this thesis was funded under a New Zealand National Research Advisory Council Post-graduate Scholarship. The New Zealand Forest Service administered the scholarship. I would like to thank the NZFS for the opportunity to study at Oregon State University and to carry out this research. I would also like to thank members of the Forest Research Institute Harvest Planning Group who often provided information and assistance at short notice over long distances.

I am grateful for the valuable assistance provided by my major professor, Eldon Olsen. Eldon was a great sounding board for ideas and gave prompt and concise advice when it was needed. Some of John Sessions' vast amount of "energy" rubbed off on me (as it does all of his students) and encouraged me to look further and question more than I might otherwise have done. The other members of my committee Tom West, George Brown and Logan Norris have also challenged me in expanding my field of knowledge.

I have been extremely lucky to have such an understanding and supportive family while I have been carrying out this research project. My deepest appreciation is sincerely given to my wife, Robyn, who contributed as much effort holding together a family and a household as I spent on the research project. Lost time can not be replaced but to my sons, Steven and Michael, I promise many fishing and camping trips in an attempt to do so.

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PREFACE

Justification

The Forestry Council at the 1981 New Zealand Forestry Conference recommended that high priority be given to a greater research effort in the fields of harvesting and log segregation for both flat and steep terrain plantations. This thesis addresses issues related to steep country harvesting and log segregation.

English spelling

New Zealand does not follow the American style of spelling; rather it follows the "Queen's" English style. Unless I have been making a direct quote of an American author I have attempted to use the "Queen's" English spelling throughout this thesis.

Manuscript format

Chapters 2 through 5 are written in a self-contained manuscript format to facilitate publication in scientific journals.

An Economic Analysis Of Final Log Manufacturing Locations In The Steep Terrain Radiata Pine Plantations Of New Zealand.

CHAPTER 1. INTRODUCTION

1.1 PLANTATION FORESTRY IN GENERAL

New Zealand, with a population of just over three million people, is dependent for its livelihood on the export of agricultural products. Since the 1950's however, forestry - as distinct from agriculture - has played an increasingly important role in the economy. The export of forest products already ranks fourth in value after meat, wool and dairy products, earning New Zealand $613 million in overseas funds in the year ending June 1984 (Clifton, 1985). As a result of a government administration commitment made in the early sixties to vastly increase the country's exotic forest estate there will be a substantial increase in the amount of wood available for export in processed or unprocessed form beginning in the mid-1990's (Figure 1-1). The available roundwood surplus will eventually be of the order of ten to twenty million cubic metres per annum. Virtually all this wood will be of one species, _Pinus radiata_ (D. Don), a California pine which was relatively obscure when

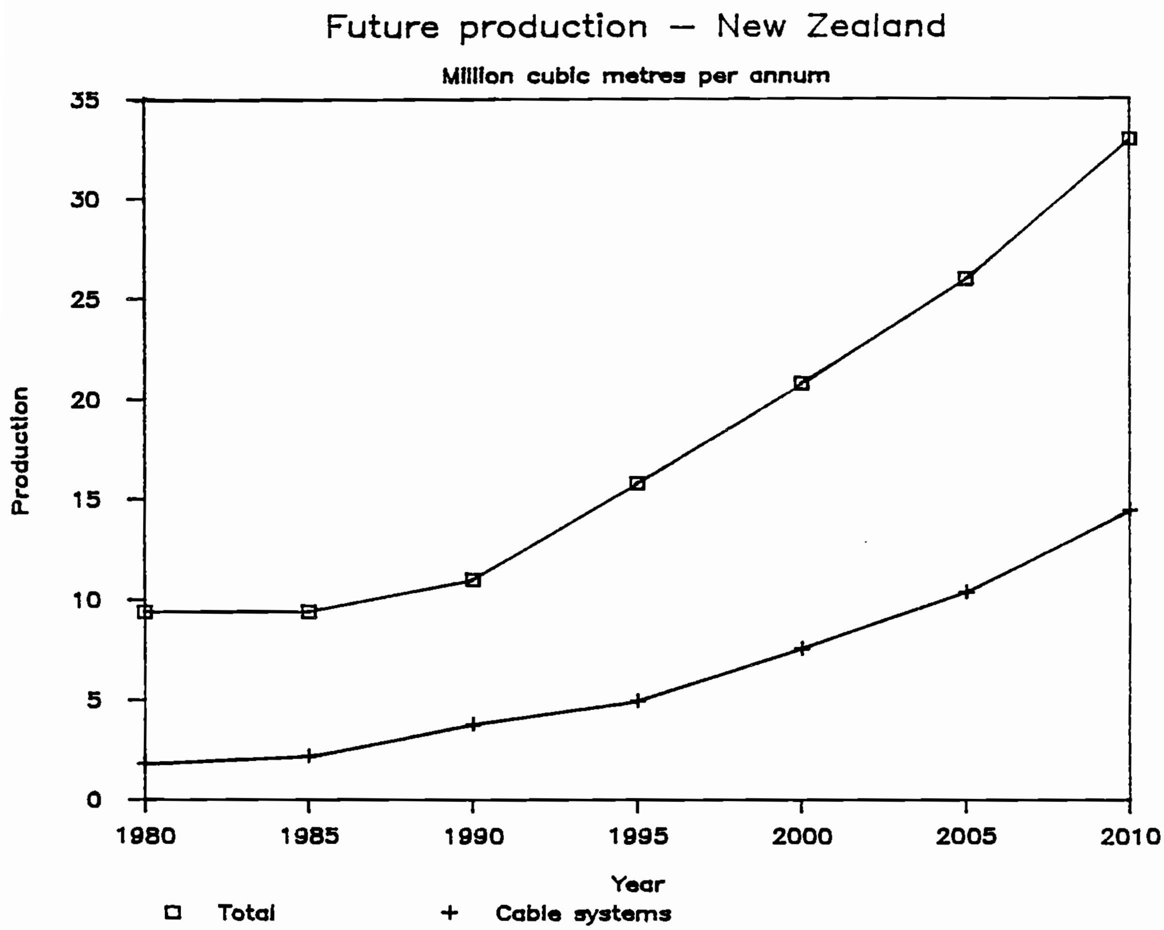

Figure 1-1 Future production from New Zealand's plantation forests.

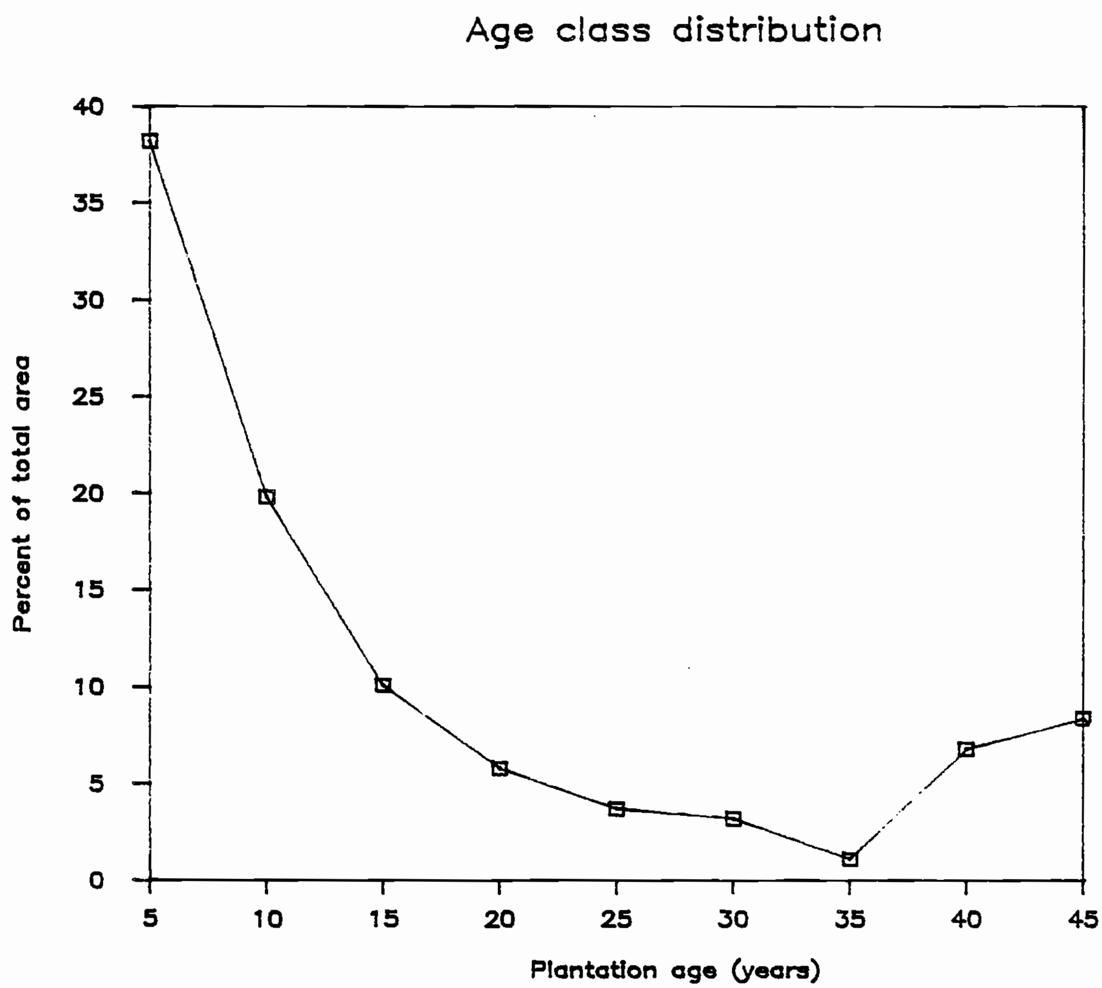

Figure 1-2 Age class distribution for New Zealand's plantation forests.

introduced into New Zealand in the middle of the last century.

In the mid-1800's New Zealand's indigenous forest covered 53 percent of the land area. The forests appeared to be inexhaustible. By 1913 so much land had been cleared of forest and public concern for future wood supplies was such that the Government set up a Royal Commission on forestry. The Commission recognised that not only were the indigenous forests exhaustible, but also the indigenous tree species were not suitable for afforestation. It strongly recommended the planting of exotics, especially radiata pine.

By 1936 317,000 hectares of exotic forest had been planted by the Government and private companies. At this stage the rate of new establishment declined. Little planting was carried out between 1937 and 1961. Early in the 1960's interest in plantation forestry increased again. The nation was starting to become concerned about its dependence on meat and wool products and it was becoming obvious that radiata pine had good export prospects. A second planting boom began. Figure 1-2 shows the great imbalance in the distribution of age classes for New Zealand's plantation forests.

The large increase in timber harvested from the exotic forest plantations has been mirrored by a concomitant decrease in volume harvested from the indigenous forests. For the year ended 31 March 1984 the indigenous cut only comprised 6% of the national total and is still falling rapidly.

1.2 IMPORTANCE OF STEEP COUNTRY PLANTATIONS

Levack (1978) pointed out the growing importance of steep country plantations at the 1978 Logging Industry Research Association cable logging seminar . He estimated that the percent of plantations that would be cable logged would increase from the then current figure of about 14% to about 40% by the year 2010. An increase in the relative proportion of steep country harvested, combined with an overall absolute increase in total volume harvested, suggested that there would be about an eight-fold increase in the amount of wood coming from steep country (Figure 1-1).

Carson (1983) has suggested that New Zealand's "steep country logging problems" would rise dramatically unless the cable logging skills of both planners and practicioners were vastly improved. He pointed out similarities between New Zealand in the 1980's and the United States in the 1960's. In the U.S. the high cost of harvesting steep country plus the rising tide of environmental concerns (often stimulated by the poor logging practices brought on by the difficult conditions) caused the U.S. Forest Service to consider blocking large segments of land out of its productive land base. The timber was there but the value was not. He suggested that unless all options are carefully examined New Zealand may find that much of its steep country plantations may not be economically or environmentally feasible to harvest. A rule of thumb is that it is about twice as expensive to harvest wood from steep country as it is from flat country.

1.3 "NORMAL" LOGGING PRACTICES

Because of degrade problems from sapstain, radiata pine is usually felled less than a month before extraction. It is currently common practice on both flat and steep terrain to extract wood in a tree-length or full-tree form to large landings (0.1-0.3 hectares) where logs are then cut-to-length (manufactured) and segregated. The 1974 survey of the New Zealand logging industry found that 30 percent of organisations extracted full-tree (no delimbing, topping, or cutting-to-length at the stump) and 70 percent extracted tree-length (delimbed and topped but not cut-to-length at the stump) on steep country (Fraser and others, 1976). Logs are temporarily stockpiled on the landing until log trucks arrive. Rubber-tyred front-end loaders are usually used to stockpile logs and load the trucks. From five to as many as twenty log-types may be sorted on the landing.

Until recently the prime concern of logging managers has been to maintain a high level of productivity at the least possible cost (Ellis, 1985). Many logging operations work under incentive schemes which are primarily based on production targets.

1.4 ALTERNATIVE HARVESTING METHODS

Myers (1986) has quoted Tony Grayburn, the forest resources division manager of NZ Forest Products (one of the largest forest companies in New Zealand) as saying that "large landings will not be tolerated for much longer, either by environmentalists or forest owners". Extracting logs, which had been manufactured at the stump into their final form, to small landings will become much more common. Grayburn has said that the need for more research into the log landing phase of the harvesting system is one of the most important issues facing the logging industry today.

Somers (1986) has reported that Bryce Heard, the logging and transport manager of Tasman Forestry (the largest forest company in New Zealand), believes that central log processing yards might become commonplace in some areas. Semi-processed trees could be taken to small roadside landings and then trucked to processing yards where the high-value pruned buttlogs and sawlogs could be cut for maximum grade/value recovery.

New Zealand has limited experience with alternative options for steep terrain harvesting other than tree-length logging to large landings. In view of the importance that steep country harvesting may play in the overall economics of New Zealand's export oriented forest industry, the Forestry Council, at the 1981 NZ Forestry Development Conference, recommended that high priority be given to a greater research effort in the fields of harvesting and log segregation. This thesis concentrates on the three alternatives mentioned above:

- final log manufacturing at the stump and log-length extraction to small landings,

- tree-length extraction to, and final log manufacturing on, large landings,
- partial processing at the stump, extraction of long-log lengths to small landings, and trucking to central processing yards for final log manufacture.

1.5 CONSIDERATIONS

When steep country harvesting operations are being planned the aim should be to define the best environmentally acceptable plan with the best safety and best logging economics. The following factors should be considered when selecting from alternative log manufacturing and segregation locations:

(1) value recovery - will the harvesting system effect the amount of value that can be obtained at the final log manufacturing location ? And, if so, by how much ?

(2) harvesting system productivity - what level of productivity can be expected if logs are prepared at alternative locations ?

(3) total harvesting system costs - will trade-offs in some phases of the operation be compensated for by gains in other phases ? What differences in costs can be expected ?

(4) land taken out of production - less land is taken out

of timber production by some alternatives. What are the economic consequences of this ?

(5) environmental/visual - large landings are difficult to locate and may require more roading to reach them than small landings. Increased sediment loadings to streams could occur because of the increased roading density. Large landings may not be visually acceptable to some people.

(6) soil nutrient status - what effect would the alternative locations for final log manufacture have on the redistribution or removal of nutrients from the site ? Would any changes in methods cause an increase or decrease in the amount of fertilizer normally applied to radiata pine plantations ?

(7) ergonomics/safety - manufacturing logs on steep country can be both dangerous and hard work. What are the relative differences between alternative log manufacturing locations ?

This thesis only addresses in detail the first four of these considerations which can all be easily quantified in economic terms. Issues relating to ergonomics, safety and environmental considerations are occasionally touched on throughout the thesis. A recent report by Messina and others (1985), entitled "The nutritional consequences of forest harvesting with special reference to the exotic forests of New Zealand", examines considerations related to the soil nutrient status. Nutritional consequences will not be considered further in this thesis.

1.6 WHAT EACH CHAPTER COVERS

Chapter 2 looks at techniques for the assessment and control of log value recovery in New Zealand's plantation forests in general. The importance of controlling value recovery is quickly identified. A value audit system called AVIS (Assessment of Value by Individual Stems) is described in detail. AVIS was used extensively for analysis in the following two chapters. The use of statistical quality control techniques along with AVIS is also examined. The chapter ends with the suggestion that the future could soon see the introduction of handheld computers at the stump to aid in log bucking decisions and improve value recovery.

Chapter 3 compares value recovery when final log manufacturing is carried out at the stump versus on a large landing. The performance of three log manufacturers was measured in the field at both the stump site and on a large landing. AVIS was also used as a reference standard against which their performance could be related. The level of value recovery, sources of value loss, differences between log manufacturers, and differences between log manufacturing location were identified.

Chapter 4 examines the potential value recovery that could be obtained if the final manufacturing of logs were carried out in a central processing yard. Tree-length radiata pine is too long to be trucked without some initial cuts being made. Initial cuts preempt future log manufacturing decisions. Three fixed length bucking patterns were analysed to obtain a measure of expected volume and value losses, changes in product supply, and potential value recovery.

Chapter 5 describes a stump-to-milldoor harvesting simulation model (PROSIM) that was developed to examine various log processing options. Harvesting of logs cut from six log bucking patterns and extracted by three types of yarding systems from four harvest units were simulated. Differences in productivity and total system cost are highlighted in this chapter. The sensitivity of costs to some of the assumptions made in the model are also described. Final manufacturing of logs at the stump, on a large landing, and at a central processing yard were examined.

Chapter 6 includes an overall discussion of the economics of alternative log manufacturing locations. The results of stand level and forest level analyses are reported. The effect of land taken out of production by large landings is also examined.

The reviews of the literature and the results reported in this thesis will help to answer some of the questions related to steep country planning and harvesting. Many more points of clarification and questions still need to be answered, however.

CHAPTER 2. TECHNIQUES FOR THE ASSESSMENT AND CONTROL OF LOG VALUE RECOVERY IN THE NEW ZEALAND FOREST HARVESTING INDUSTRY.

ABSTRACT

The need to control value recovery in the New Zealand forest harvesting industry is strongly evident from recent research carried out in this area; Significant value loss can occur which could have a large impact on the profitability of both the domestic and export-oriented forest industry. Suitable techniques for the assessment and control of log value recovery are discussed in this paper. Combining log value optimisation routines, such as the AVIS system, with statistical quality control techniques, such as $\bar{X}$ or R control charts and double-sampling, should provide an acceptable basis for a good value recovery control programme. Further research is required, however, to identify the most suitable sampling patterns - frequency and size - and value control techniques for the New Zealand forest harvesting industry.

2.1 INTRODUCTION

New Zealand, with a population of just over three million people, is dependent for its livelihood on the export of agricultural products. New Zealanders have come to be rated among the worlds most efficient and successful farmers. Since the 1950's, however, forestry - as distinct from agriculture - has played an increasingly important role in the economy. The export of forest products already ranks fourth in value after meat, wool and dairy products. As a result of a commitment made in the early sixties to vastly increase the country's exotic forest estate there will be a substantial increase in the amount of wood available for export in processed or unprocessed form beginning in the mid-1990's. The available roundwood surplus will eventually be of the order of ten to twenty million cubic metres per annum. Virtually all of this wood will be one species - Pinus radiata. (Elliot and Levack, 1981).

New Zealand has invested a considerable sum of money and effort into intensively managing its radiata pine plantations to produce high quality timber for the world market. It will be vital, if a competitive advantage is to be maintained in the world markets, that the potential log products be recognised and segregated. This will be required by our domestic processing industries and log export markets so that the greatest possible value is recovered at the least possible cost (Tustin, 1983).

2.1.1 The Profit Equation

The objective for both the government and private forestry sectors in New Zealand is to make a profit. Traditionally the New Zealand forest harvesting industry has been primarily concerned about the costs of extracting and manufacturing trees into logs and the total volume recovered. New Zealand was not alone in the attitude that if you wanted to increase profits you should increase your volume recovery and reduce your costs (usually be increasing productivity). A perusal of the forest harvesting literature of many countries around the world, including the United States of America reveals that costs and volume recovery seem to be the factors most discussed and by implication the factors which should be controlled to maximise profits. The profit equation has another component however - value. A simple profit equation could be written:

$$\text{Profit} = \text{Volume} \times (\text{Unit Value} - \text{Unit Costs})$$

The value component often seems to be relegated to last place in importance. However, in New Zealand, since the time span between felling and delivery at a mill is measured in weeks, log values are known with relative certainty (compared with some parts of the USA). Therefore the value component should receive more consideration. Only recently has the industry become concerned about the amount of value recovered from the forests.

2.1.2 Importance of controlling value recovery

By the time a tree is felled, extracted, manufactured into log lengths, and loaded on truck in New Zealand up to 40% or more of its standing value could be lost through poor harvesting techniques (Murphy, 1983). Table 2-1 shows a breakdown of these value losses as determined from field studies in New Zealand (Murphy, 1982 & 1984; Geerts and Twaddle, 1985). The similar levels of loss found in American literature (Pease, 1982; Craig, 1982; Garland, 1985) indicate that felling breakage, high stumps, breakage during extraction, and damage during loading operations are sources of value loss about which logging managers in any country should be concerned.

Table 2-1. Sources of value loss in harvesting operations

Source	Value Loss (% of standing value)
Thinning damage	1 - 2
Felling breakage in the top portion of the tree	4 - 7 *
High stumps and butt damage	4 - 5
Extraction breakage and damage	1 - 2
Log manufacturing	20 - 25

* Felling breakage can be double these losses on steep broken terrain.

In New Zealand and elsewhere, the area with the greatest potential for minimising the large amount of value loss is log-manufacturing. This fact is not only newly discovered however. In 1913 R.C. Bryant wrote in his textbook on American logging practices "Log-makers frequently do not give sufficient attention to securing quality as well as quantity.... A system by which timber is cut for quality as well as quantity means an increase in the percentage of the higher grades, more timber per acre and prolonged life to the operation (through greater profits)." More recently, Steve Conway (1976) wrote about U.S. logging practices, "In the past (and even to a certain extent today), logs were cut without regard to end use. ... Least cost was, and unfortunately still is in all too many cases, the main objective. ...Failure to cut for end use can result in the loss of millions of dollars to the (forest) industry every year". Lebevre (1976) pointed out that the British Columbian forest industry was also losing millions of dollars per year from "improper log lengths originating at the woods landing and the sawmill bucking station".

Ensuring that the maximum value is obtained from each tree during the log manufacturing phase is not an easy task for any person, even under the best of conditions (and a logging site can hardly be called the

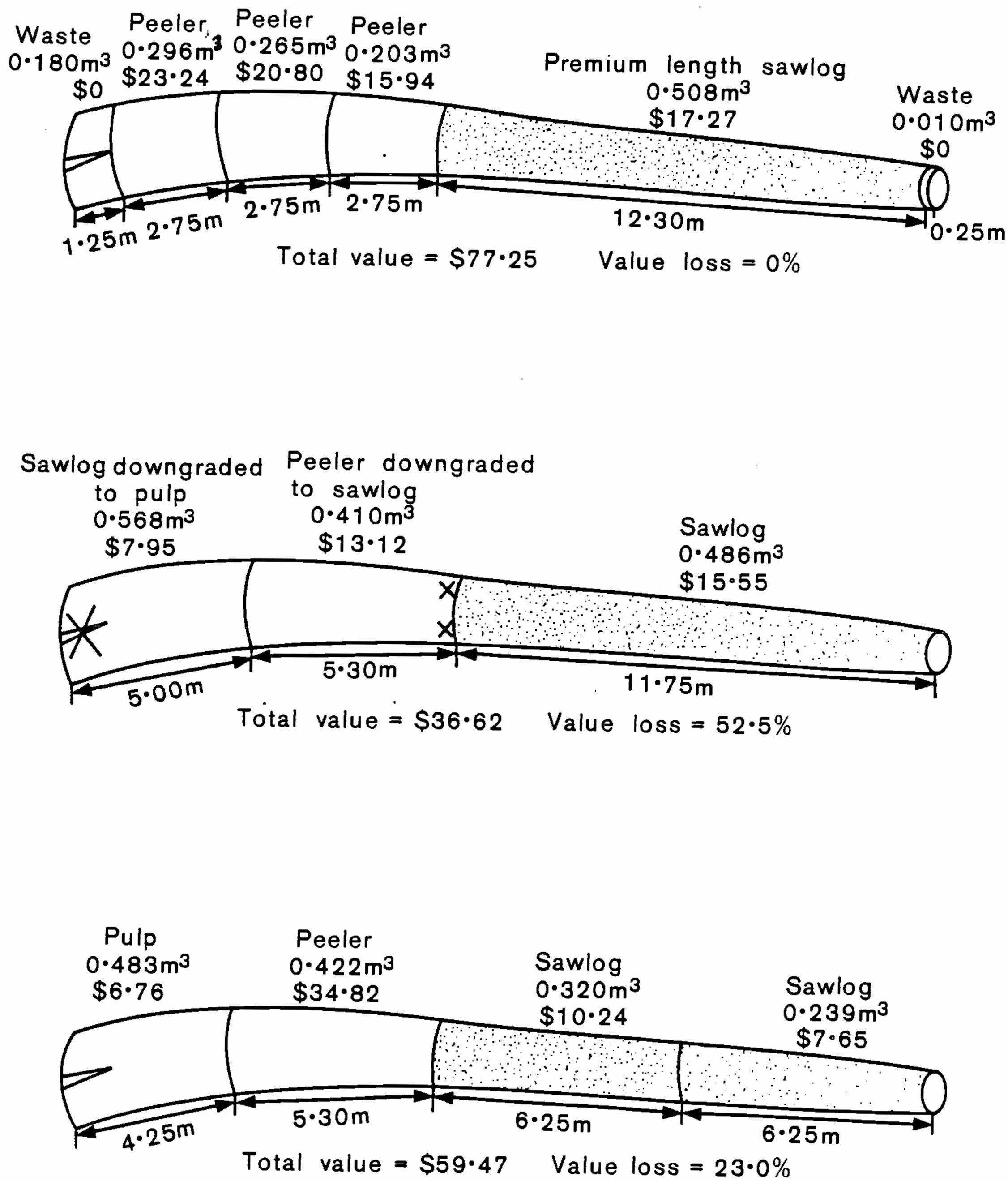

Figure 2-1 (a) Optimal cutting pattern (top),
(b) Sub-optimal cutting pattern (middle). Some logs do not meet specification.
(c) Sub-optimal cutting pattern (bottom). Individual logs meet specification.

best of conditions); the working conditions are often harsh and dangerous, the raw material is an extremely variable product (no two trees are exactly alike), and the log specifications are often complex.

Figures 2-1a, 2-1b, and 2-1c give an indication of the decision-making problems a log-manufacturer is confronted with when trying to optimise the value of a stem. Figure 2-1a shows a tree cut up in such a way that total value is maximised - tree length, taper, defects, branching, sweep, and other quality characteristics have been optimally matched with allowable log specifications and market prices. The value loss for this cutting pattern is 0%.

Figure 2-1b shows the same tree which has been cut into logs in a sub-optimal way. Some of the logs are out of specification and would have to be downgraded and re-manufactured, incurring a further loss. Over 52% of the potential value was lost with such a cutting pattern. Some discussion of methods to control out-of-specification logs has occurred in New Zealand (Twaddle, 1986a, 1986b). This type of sub-optimal log-manufacturing is easier for a logging supervisor to recognise and control than that shown in the next figure.

Figure 2-1c again shows the same tree cut in a sub-optimal manner. Although each individual log is within allowable specifications this is not the best cutting pattern for the tree as a whole. Twenty three percent of the value would still be lost with this cutting pattern. This highlights a significant problem in controlling value recovery; how to determine the optimal pattern for each and every different tree. This problem will be addressed in more detail later in this paper.

2.2 QUALITY CONTROL PROGRAMMES IN THE FOREST INDUSTRY

The value recovered from a tree can be thought of as a quality of the tree, just as the amount of cereal that ends up in a Cornflakes packet can be classed as a quality of that packet. Quality control programmes have been used, and still are being used, successfully in a wide range of industries in the U.S.A. for over 50 years - e.g., aircraft, clerical and accounting procedures, brewery, electronics, medicine, and mail handling to name but a few (Am. Soc. for Q.C., 1955). Quality control programmes are also used in the pulp and paper (Noble, 1952), central sortyard (Duffner, 1980), sawmilling (Beck, 1980; Brown 1982), and, to a certain extent, the forest harvesting industries (Conway, 1973; Craig, 1982). Very few forest harvesting organisations in New Zealand have a formal quality control programme to ensure value maximisation. Papers by authors such as Conway (1973), Beck (1980) and Craig (1982) give some guidelines for implementing a good quality control programme in a forest harvesting organisation. Their guidelines for implementation of a management control system are amalgamated below.

1. Personnel responsible for log-making should receive intensified on-the-job training in log grading

and value maximisation.

2. Best or optimum performance should be defined, then realistic goals established.

3. Value recovery performance should be monitored on a formalized, routine basis.

4. Performance should be analysed and expressed in economic terms where possible.

5. Logging supervisors and crew members should receive frequent and timely feedback on performance.

6. Logging supervisors should help establish corrective action plans.

7. Performance must be documented to provide feedback.

2.2.1. Determining the best or optimum performance

Extensive literature reviews of techniques for optimal conversion of stems have been recently done by such authors as Briggs (1980) and Lawrence (1986). Optimising the value recovery for trees is often done by one of two main operations research techniques; dynamic programming (DP) or linear programming (LP). Other techniques such as integer programming (IP) (Ramalingam, 1976) and network analysis (Sessions and Layton, 1986) have been proposed. The reader is referred to Briggs's doctoral dissertation (1980) for a detailed discussion of the application of DP, LP and IP techniques. A synopsis of the techniques is given below.

The first attempts at formulating and predicting optimal stem conversion in the United States were made by Clemmons (1966), who proposed using dynamic programming techniques, and Forster and Callahan (1968), who suggested a linear programming approach to determine the optimal log-to-market alternatives.

Following the work of Pnevmaticos and Mann (1972) in Canada, dynamic programming has proved to be the most popular of the techniques for optimising log value recovery. They believed that dynamic programming is better than linear programming since it "can incorporate deterministic and probabilistic elements, can handle both linear and non-linear functions, and the solution yields a policy for all possible conditions". They described an algorithm for manufacturing logs which were all one grade. Briggs (1977) and Dykstra (1984) describe a similar algorithm. Several papers presented at a KWF-IUFRO meeting held in Germany in 1979 discussed other algorithms suitable for dynamic programming analysis of logs (Geerts, 1979).

Maximisation of value based on single tree models, however, can lead to sub-optimisation. Linear programming allows constraints to be imposed on the number and types of logs produced from a stem. Smith and Harrell (1961) developed a linear programming approach which allows inclusion of constraints. The main problem with this approach is that it is necessary to specify all possible log-manufacturing patterns in advance. Because of the variability of trees this places a heavy burden on the analyst and leads to a very large number of linear programming activities. Bare and others (1979) and Eng and others (1986) have proposed that a combination of dynamic programming and linear programming would allow the best of both worlds. The former would be used to evaluate "optimal" log-manufacturing patterns given several sets of specifications and the latter would then be used to select the best of these patterns within the constraints. A computer program for a combined technique such as this would be very large and complex, and would require a large amount of data to run successfully.

Ramalingam (1976) proposed that a branch-and-bound method could be used to solve the optimal stem conversion problem. The utility of the branch-and-bound method derives from the fact that, in general, only a small fraction of the possible solutions need actually be enumerated; the remaining solutions being eliminated through applying the bounds which establish that such solutions cannot be optimal. Bare and others (1979) have shown however that the procedure proposed by Ramalingam fails to determine the optimal solution under certain price and length conditions.

Briggs (1980), in his summary of the literature, suggests that dynamic programming may be the most useful and practical technique for determining the optimal solution to the stem conversion problem.

2.2.1.1. The AVIS system

In New Zealand several value optimising packages have been developed (Deadman and Goulding, 1979; Eng, 1982, Eng and Daellenbach, 1985, Geerts and Twaddle, 1985), all of which incorporate dynamic programming algorithms. Of these packages, the AVIS package developed by Geerts and Twaddle (1985) is the most applicable to the forest harvesting industry and could readily be turned into the core of an effective value recovery control system.

AVIS is an acronym for Assessment of Value by Individual Stems. As the name implies it is an individual tree based rather than a stand based value audit system. It compares stem by stem the log-making decisions made during harvesting operations with an optimal solution calculated using a dynamic programming algorithm. AVIS can assess the level of value loss through sub-optimal log-making, detect the patterns in worker cutting decisions and the type of defects they tend to overlook. It can also be used for quantifying other sources of value loss such as felling breakage, thinning damage and high stumps. It also has the potential to be used as an education aid to illustrate the effect on stem value of the application of different cutting patterns and the effect of changing products and product specifications (Threadgill and Twaddle, 1986).

AVIS comprises a field procedure for gathering of stem data, and a set of eight computer application programs for analysing these data.

AVIS FIELD FORM

DATE 15/ 8 /86

TREE No. 53 | STUMP HEIGHT (cm) 26 | SLOVEN LENGTH (m) 0·3

PIECE No. 1 | DBHOB (cm) 49 | SLOVEN QUALITY S

TAPER

INTERVAL LENGTH (2, 3 or 4m) 3 | PIECE LENGTH (m) 26·2 | TOP HEIGHT + 15·9

LENGTH (m)	0	3	6	9	12	15	16	21	24				SEDcm
DIAMETER. (OB)(cm)	56	47	44	42	39	36	32	30	27				25

QUALITY

DEFECT CODE	SLAB		BR	BR>6	BR	BR>14							
QUALITY CODE	S	A	S	L	S	R							B
LENGTH (m)	0·5	5·6	16·8	16·8	20·5	·	·	·	·	·	·	·	·
CUT ZONE	1·5–3·0/1		15·6–18·1/2										

COMMENTS:

Figure 2-2 AVIS field form.

The field procedure consists of two segments. The first is a dimension and quality cruise on felled trees to establish the size and quality parameters of a stem. The second is the log cruise which measures the actual output from a stem when it is manufactured into logs.

Figure 2-2. shows an AVIS field form which has been completed for one piece of a single tree. Data is recorded on such peripheral features as a tree code, stump height, and diameter breast height; on dimension features such as tree taper and length; and on quality features such as defect and quality codes, lengths, and cut zones.

The log cruise is a record of what logs are produced from each measured stem. This represents the achieved log manufacturing solution as distinct from the solution produced by the dynamic programming algorithm within the body of the AVIS computer program. Figure 2-3. shows the type of information recorded for the same piece shown in Figure 2-2. The logs are recorded in the identical sequence that they fall within the piece.

The "AVIS System User's Guide" describes in detail the set of computer programs for analysing the field data. The eight programs require about 300K for storage

SKID CONCILIATION

DATE 17/8/86

TREE No.	TREE No.	TREE No.	TREE No.	TREE No
53				
PIECE No.	**PIECE No.**	**PIECE No**	**PIECE No.**	**PIECE No.**
1				

Starting at the butt record log type (including waste), and length

	type	length	type	length	type	length	type	length	type	length
1	W	0.25								
2	P	5.31								
3	S	8.60								
4	L2	4.54								
5	S3	4.90								
6	U									
7										
8										

COMMENTS :

Figure 2-3 Log outturn form.

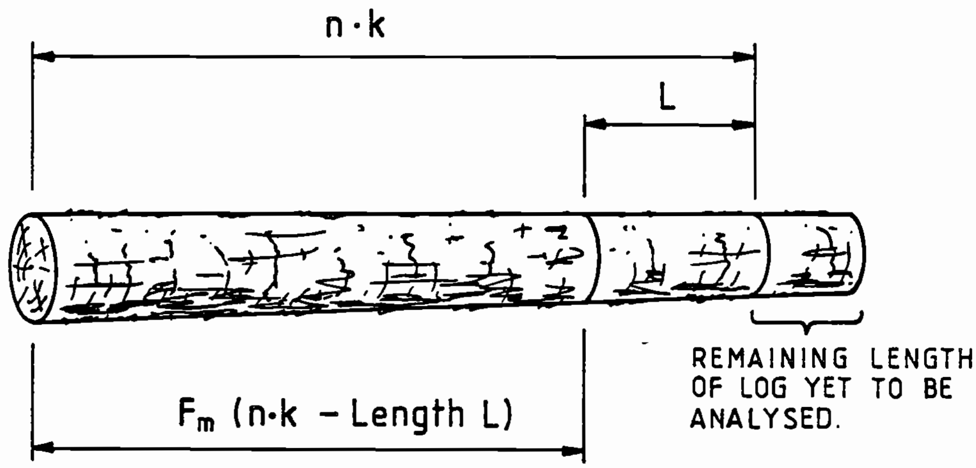

Figure 2-4 AVIS log bucking strategy.

and are written in VAX-11 FORTRAN. The optimising routine uses the stem dimension and quality characteristics combined with a set of log specifications and prices input by the user to determine which is the best way to cut up the stem to maximise total value.

The recursive relationship used to optimise value is important since it is the heart of the AVIS system (Figure 2-4). Mathematically it can be written as:

$$\underbrace{Fn(n\cdot k)}_{\boxed{\text{Optimal value for current length } n\cdot k}} = \underbrace{\mathrm{Max}_{L\ S}\left(\sum_{i=m\cdot k}^{n\cdot k} V(i)\right) P(L) - c}_{\boxed{\text{Value of candidate logtype } L}} + \underbrace{Fm\ (n\cdot k - \mathrm{length}(L))}_{\boxed{\text{Optimal value before logtype } L \text{ was considered}}}$$

where

n	is the current stage number
k	is the stage length, typically 1 decimetre
n·k	is the product of n and k
L	is the candidate logtype
S	is the set of all logtypes

m	is the stage at the base of the current trial state
V(i)	is the sectional volume at section i along the stem
P(L)	the value per unit of volume of logtype L
c	is the cost of a sawcut
Length (L)	is the length of the candidate logtype
Fm	is the value of the optimal subpolicy for cutting the stem segment between the stump (or last compulsory cut) and the base of the current logtype.
Fn	is the value of the optimal policy given by the state at stage n

and

F0 =0

Verbally it has been described by Threadgill and Twaddle (1986) as follows:

> The objective is to maximise the value of the stem given the value per unit volume of a set of logtypes (including their length and quality characteristics) and the cost of a sawcut. The decision variables are the logtypes able to be cut.

The stem is considered to be made up by a sequence of stages (n=0,1,...,N). The stages begin at the base of the stem (the large end). At each stage the state is the distance (in stages) between the current stage and the stem base. Consequently there is a one to one relationship between stage and state.

Starting from stage 1 (since Fn=0 when n=0), the logtype that optimises Fn is enumerated. (This is the optimum value up to stage n). Thus optimal subpolicies are formed at every stage along the stem length. By building up a set of subpolicies at every stage, the optimal policy can be formed. This conforms to the principle of optimality as proposed by Bellman (1957). Enumeration at every stage is carried out by looking at every state back from the current stage to the butt of the stem (or the positon of the last compulsory cut) and checking if the candidate logtype conforms to the length requirements. If it does, quality between the current stage to the beginning of the candidate logtype is checked. Minimum small end diameter (sed), maximum sed and maximum large end diameter are also checked to see if they conform. If the logtype is an allowable assortment then the value is calculated. This value is added to the value calculated at the stage where the logtype commences. This is done for all allowable logtypes over all stages back. The logtype generating the maximum cumulative revenue forms the optimal subpolicy at the current stage. The same process is carried out for all stages along the stem's length. After arriving at the last stage the placement of cuts along the stem and the optimum logtypes to be cut is determined by backward recursion.

The computer output of the optimal cutting pattern and value for the piece recorded in Figure 2-2 is shown in Figure 2-5. Length, position, logtype, volume, and value are given.

Figure 2-6 gives the actual cutting strategy from the large end with its associated value for a different piece to that shown in Figure 2-5. Some of the logs do not meet specification rules. The "LOG UPGRADING" section to the right of the actual solution shows exactly where the logs in this piece do not conform to the log specification rules (log upgrading does not occur on all pieces). The type of information presented in Figure 2-6 would be of great help to a log value quality control manager.

OPTIMAL CUTTING STRATEGY FROM THE LARGE END

# CUT	SED	ACTUAL LENGTH	CUM. LENGTH	TYPE NAME ASSORTMENT	VOLUME (UB)	VALUE ($)
1	471	0.50	0.50	WASTE	0.09	0.00
2	412	5.20	5.70	PRUNED SAWLOG	0.78	66.13
3	305	12.20	17.90	UNPRUNED SAWLOG 'L'	1.31	81.33
4	259	5.80	23.70	PULPWOOD	0.37	3.70
REST	233	2.50	26.20	PULPWOOD	0.12	1.16
				TOTAL	2.66	152.32

Figure 2-5 Optimal cutting pattern.

CUTTING STRATEGY SKIDS FROM LARGE END

#	LENGTH		TYPE	VOL	VALUE	LOG UPGRADING					
						DIAM		QUAL		LENGTH	
CUT	ACTUAL	CUM.	NAME	(UB)	$	<SED	>LED	Q	VOL	<MIN	>MAX
1	7.92	7.92	PEELER	0.84	69.46	0.7		S	0.31		0.0
2	5.08	13.00	SAWLOG	0.44	24.26						
3	11.07	24.07	SELECT H	0.70	45.73	5.2					0.1
REST	8.88	32.95	PULP	0.29	2.95						
			TOTAL	2.28	142.41						

Figure 2-6 Actual cutting pattern.

2.2.2. Statistical Quality Control

The AVIS system has been used successfully in several research projects in New Zealand (Geerts and Twaddle, 1985; Twaddle, 1984a & 1984b). Each of these has involved the measurement of several hundred trees. Although the results were of much value to the harvesting organisations involved, the procedure would not be entirely suitable for a quality control management programme without some modification. The modification would undoubtedly include the use of statistical techniques to allow a reduction in the number of trees that would have to be measured - and as a result the cost of quality control.

In any production process a certain amount of inherent or natural variability will always exist. This natural variability or "background noise" is the cumulative effect of many small, essentially uncontrollable causes. A process that is operating with only chance causes of variation present is said to be in statistical control. When variability arises due to operator errors or improperly adjusted equipment, which are termed "assignable causes", the process is said to be out of control. A major objective of statistical quality control is to quickly detect the occurrence of assignable causes or process shifts so that investigation of the process and corrective action may be undertaken before very many nonconforming units are manufactured.

Statistical techniques, with respect to log value control, have had very little use in the forest harvesting industry of New Zealand. Some of the reasons for this have been the problems of large variability in the raw material and market requirements, and the lack of a suitable technique for establishing a standard or base. Little can be done about raw material and market variability but the AVIS system could undoubtedly now be used to provide a suitable standard. Although statistical quality control techniques have yet to be combined with the AVIS system some possibilities can be conjectured.

2.2.2.1 $\bar{X}$ and R Control-Charts

Statistical control-charts have been used by a wide range of industries for a long time because they are effective and are relatively easily understood by both management and the employees. They provide a means of documenting and communicating performance relative to defined standards. Craig (1955) writes "The real heart of statistical quality control is process control. And for process control the control chart is a remarkably well designed and effective instrument."

Many types of statistical control charts have been developed by industry e.g. $\bar{X}$ charts, R and S charts, acceptance control charts, cumulative sum charts (Freund, 1962), and geometric moving average control charts (Roberts, 1959 & 1966; Wortham and Heinrich, 1972 & 1973). The $\bar{X}$ and R charts are currently the most commonly used type. They are probably the types with the most applicability to the forest harvesting industry.

When dealing with a quality characteristic that is variable (e.g. percentage of value lost), it is a standard practice to control both the mean value of the quality characteristic and its variability. An $\bar{X}$ chart is usually used to control the mean quality level. Performance variability can be controlled with either a standard deviation control chart (S chart) or a range control chart (R chart). The R chart is more widely used since it is easier for the workers and management to understand, and it is almost as efficient as an S chart at low levels of sampling intensity. $\bar{X}$ and R charts are discussed in detail in many quality control texts (e.g. Feigenbaum, 1951; Montgomery, 1985).

The hypothetical charts in Figures 2-7. and 2-8. show how $\overline{X}$ and R charts could be used for controlling log value recovery. Since the control limits on the $\overline{X}$ chart depend on and are made meaningful by the performance variability, it is best to begin with the R chart when setting up $\overline{X}$ and R control charts. Value loss is calculated as follows:

$$\text{Value loss (percent)} = \frac{100\ (\text{optimal \$ value} - \text{Actual \$ value})}{\text{Optimal \$ value}}$$

The R chart in Figure 2-7. is based on samples of 5 stems (see footnote). Each point on the chart is the difference, or range, between the stems with the highest percentage value loss and the lowest percentage value loss. When the operation was in control it was found that the mean range was about 17%. This is the centre-line for the R chart. Most control charts have upper and lower limits. These are chosen so that if the operation is in control nearly all of the sample points will fall between them. In this case there is only an upper control limit. Less than 1 sample in 500 should fall above this limit if the operation is in control. Some of

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Sample size for control charts in many industries is 4 to 6 units. Research is required in this area to decide what would be a reasonable sample size for forest harvesting operations.

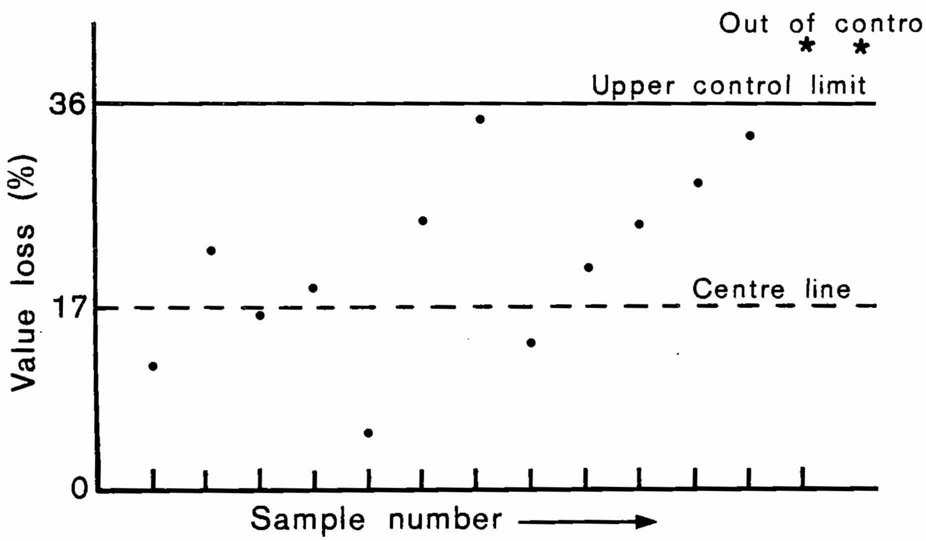


Figure 2-7 R chart for controlling variability in value loss.

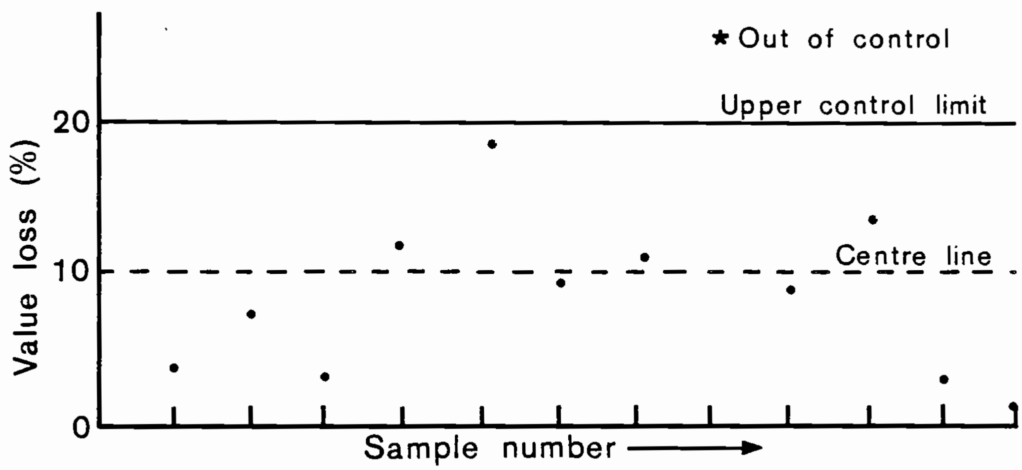


Figure 2-8 $\bar{X}$ chart for controlling average value loss.

the samples on this chart are marked as asterisks and fall above the upper control limit. It is very likely that the log-making operation is out of control at these points. The logging supervisor would know it is time to do something about the operation when this happened.

The five points immediately to the left of the first asterisk indicate a run where the operation may have been gradually getting out of control. Nelson (1985) and Montgomery (1985) describe methods for analysing patterns on control charts which help to identify such runs at early stages.

The centre-line of the $\bar{X}$ chart in Figure 2-8. (i.e. 10%) is the mean of the sample means ($\bar{\bar{X}}$) when a hypothetical operation is in control. Ideally management would hope for 0% loss but the cost of achieving perfection in any industry is often greater than the return. Changing market conditions which result in varying product specifications and values mean that the log-maker is continually operating on a new learning curve for optimal recovery patterns. It is thus unlikely that 0% value loss wil routinely be achieved.

According to the example in Figure 2-8 the logging supervisor would be prepared to accept an average loss of

19% for a sample of five stems without getting unduly concerned because the upper control limit is at 20%. A supervisor would know it is very unlikely that the value recovery operation is in control if average losses were 25-30%.

Under a value control system based on $\overline{X}$ and R control charts each log-maker would be sampled frequently - possibly once a week.

2.2.3 Double-sampling techniques

Although a small sample of trees may be adequate for determining whether the value recovery operation is out of control it may not be adequate for identifying how and why it is out of control. In the field of forest mensuration double-sampling techniques are often used to reduce the overall sample size required. The same principle could apply to value control. If the statistical quality control procedures indicate that the operation is out of control an additional sample could be taken to identify sources of value loss. Research is required in this area to identify what the original sample size and additional sample size should be for value control in the forest harvesting industry.

Before leaving the section on statistical quality control techniques it is best that a warning be passed on from people in the sawmilling industry who are using them. Martin (1982) writes "The power of statistical quality control is useless - even counterproductive - if there are variations [in the operation] that can easily be detected by the naked eye from across the mill and that are the result of .... negligence." In other words, if a system is out of control first get it into control and then use statistical quality control techniques to keep it there. A commitment by management to quality control and the provision of proper rules and tools are often the first needed steps for bringing a value recovery operation into control (Conway, 1976).

2.3 THE FUTURE

The electronics industry is changing at an incredible rate. For example, less than five years ago a 64 K micro-computer was a wonder; today micro-computers of ten times that size are very common. Similarly, handheld computers are fast replacing handheld programmable calculators. The New Zealand Forest Service is currently adapting the software of the AVIS program for use in a robust, handheld portable micro-computer. Preliminary field trials with an 8-bit Husky micro-computer indicate that the optimal solution for a 30 metre tree, given 50 logtypes, can be found in less than 10 seconds. Similar developments are underway in both Canada and Sweden (IEA,1986) and in the United States (J. Sessions, pers. comm.). Such a tool would be a valuable aid in both training log-makers and in auditing their output. One could envisage a value control system (Figure 2-9) with a market feedback mechanism whereby the prices driving the decisions about individual trees are influenced by the aggregate supply and demand of logs. Periodically (e.g., once per week), the log-makers would transfer the log product information they had gathered on their hand-held micro-computers onto a mini-computer or main-frame computer. The larger computer would then summarise the information from all of the log-makers and

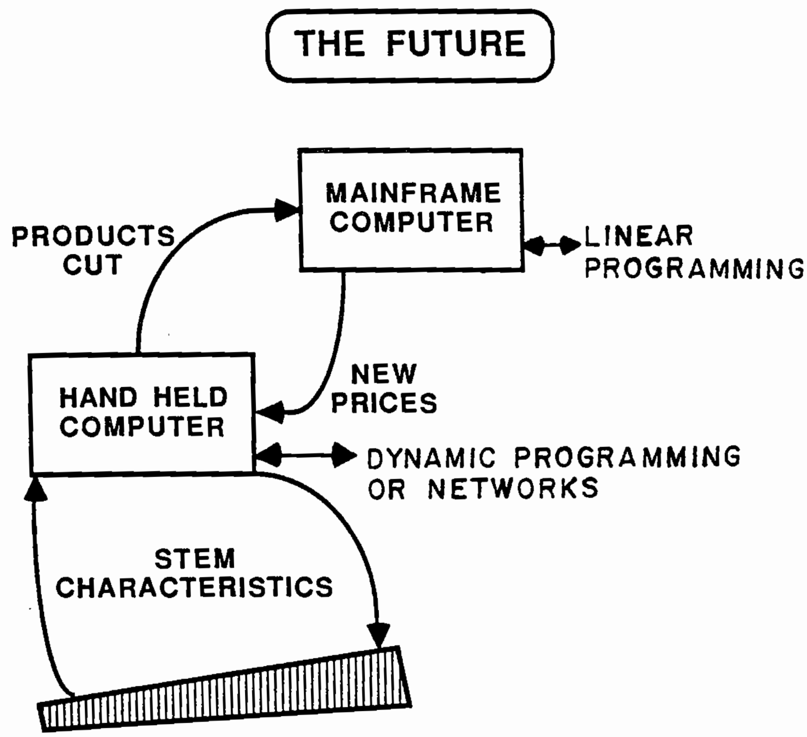


Figure 2-9 Value control system.

combine it with the current market information to calculate updated product prices. These updated prices would then be reloaded into the hand-held micro-computers for use by the log-makers during the next period. Such a value control system would negate some of the criticism of single stem dynamic programming models (Ramalingam, 1976; Bare and others, 1979) opposed to whole stand linear programming models where constraints can be imposed on the number and types of logs produced from a stem.

Statistical quality control techniques will still be needed to complement the use of hand-held micro-computers if a value control system is to be effective in the future. Having a tape does not ensure that the length of every log is measured correctly. Nor can it be expected that having a handheld computer will ensure that the stem is cut into the optimal pattern.

2.4 CONCLUSIONS

The need to control value recovery in the New Zealand forest harvesting industry is strongly evident from recent research carried out in this area. Significant value loss can occur which could have a large impact on the profitability of both the domestic and export-oriented forest industry. Combining the AVIS system with statistical quality control techniques should provide an acceptable basis for a good value recovery control programme.

The AVIS system can be used to:

- help train log-makers in value recovery techniques
- define optimum performance
- analyze performance in economic terms
- help identify sources of value loss.

Statistical quality control techniques can be used to:

- monitor performance on a regular basis
- provide frequent and timely feedback
- document performance.

Further experience/research is required, however, to identify the most suitable sampling patterns - frequency and size - and value control techniques for the New Zealand forest harvesting industry.

CHAPTER 3. A COMPARISON OF VALUE RECOVERY FROM CUTTING TREES INTO LOG LENGTHS AT THE STUMP VERSUS ON A LANDING.

ABSTRACT

One hundred and forty three trees from a forty year old Pinus radiata stand on steep terrain were marked, by three log manufacturers, at the stump for cutting into log lengths. The marks were removed then the trees were extracted to a landing. Two of three log manufacturers at the stump again marked the trees at the landing and finally cut the trees into logs.

Comparisons of value recovered indicated that there were significant differences in recovery between log manufacturers at the stump but not at the landing. Value recovery at the landing was found to be at least as good as, if not better, than recovery at the stump. There was no significant difference in value recovered at the stump and at the landing by the best log manufacturer. There was, however, a 9% improvement in recovery at the landing for the other log manufacturer.

Downgrading of potential peeler material to sawlog grades, and potential sawlog material to pulpwood grades was a major source of value loss.

Both of the log manufacturers who worked on the landing, produced a lower proportion of logs that did not meet specification, compared with the stump. Much of the reduction in out-of-specification logs was due to improved length accuracy.

3.1 INTRODUCTION

It is currently common practice on both flat and steep terrain in New Zealand to extract wood in a tree-length or full tree form to large landings where the trees are manufactured into log lengths and segregated. The 1974 survey of the New Zealand logging industry found that 30% of organisations surveyed extracted full tree (i.e. no delimbing, topping, or cutting into log lengths at the stump) and 70% extracted tree-length (delimbed and topped but not cut to length at the stump) on steep country (Fraser and others, 1976). As New Zealand expands it forest plantations, away from the relatively easy pumice region of the central North Island, onto steeper, more unstable terrain and more difficult soil types other log processing and segregation options must be considered since large landings may be too difficult or expensive to build. In recognition of the limited experience New Zealand has with other options, the Forestry Council, at the 1981 New Zealand Forestry Conference, recommended that high priority be given to a greater research effort in the fields of harvesting and log segregation.

There are several locations where log manufacture and segregation could take place - felling-site, the landing, a centralised processing yard (CPY), or at a merchandiser at the processing plant. The decision on which is the best option for particular circumstances within New Zealand will require a good understanding of how these options affect value recovery and harvesting costs.

This study focuses on a comparison of value recovery obtained from clearfelling steep terrain radiata pine plantations of approximately 3 cubic metres average tree volume.

3.1.1 Log manufacturing in general

Brown (1958) states that there are four purposes for manufacturing logs out of trees, wherever that manufacturing may occur:

- to reduce product weight per piece
- to eliminate defects and reduce haul waste
- to adapt the tree to the method of transport so that transport efficiency might be improved and cost reduced
- to meet market requirements.

For the United States Conway (1973) has stated that "bucking (log manufacturing) has become more important as timber operators, feeling the pressure from rising timber prices, a growing timber shortage, and environmentalists, try to squeeze every bit of value out of a tree".

Palm (1973) believes there are two aspects to the log manufacturing problem. One is the question of <u>where</u> in the chain of operations it is best to do the manufacturing. The other question is <u>how</u> is it best to manufacture the tree into logs. The latter question is addressed in detail in Briggs (1980) and Chapter 2 of this dissertation.

The ideal situation is one where final log manufacturing can be carried out in the mill-yard where adequate equipment and trained staff are available (Wahl, 1979). Unfortunately, in many cases trees are too large to be efficiently handled and delivered in one piece to a mill-yard. Also the luxury of a single product manufacturing operation is a thing of the past for many forestry operations (Tessier, 1974). Log manufacture and segregation could take place at felling-site (stump), the landing, a centralised processing yard, or at a merchandiser at the processing plant. Sworder (1978) believes that proper log manufacture must start in the woods and he describes techniques for getting the highest value out of a stem at the stump.

3.1.2 New Zealand experience

The option of processing trees into log lengths at the stump on steep country is now being considered for clearfelling operations in New Zealand as one of the alternatives to tree-length or full tree extraction for a number of reasons; to achieve lift over sensitive soils where deflection is poor, to minimise landing size where construction cost is high or location difficult, and to reduce the piece size where necessary to suit the machinery available for the job.

The limited experience that New Zealand has had with manufacturing logs in plantations at the stump has generally been unfavourable. The opinions and experience described below are examples of the obstacles that would have to be overcome if log manufacturing at the stump were to be succesfully implemented in New Zealand.

In the late 1960's one large logging company tried cutting trees into log lengths at the stump for extraction by a Skagit swing boom yarder. The technique was abandoned for economic reasons (Vari, pers. comm.). Also in the 1960's a series of trials were carried out on log length extraction of small piece size Douglas fir by a Wyssen skyline. One of the Logging Officers associated with the trial said that he disapproved strongly of log manufacturing at the stump on steep country because it was too dangerous, was very hard work, and branches were delimbed that would have been broken off during extraction if the trees had remained in tree-length form (Bonner, pers. comm.). In a more recent production trial of harvesting tree-length radiata pine it was found that wood wastage was higher and many log lengths were inaccurately cut. The logging manager also believed that the operation was too dangerous - radiata pine in log length form is prone to unexpectedly sliding down the hill because of its "soapy cambium, and bark that comes off easily" (Sperry, pers. comm.).

Productivity and cost issues relating to log manufacture at the stump versus on a landing will be discussed in Chapter 5. This chapter will concentrate on the influence of these two log manufacturing locations on value recovery.

3.2 STUDY OBJECTIVES

The correct selection of the best log manufacturing location for particular areas within New Zealand will require an understanding of how these locations affect log value recovery and harvesting costs. The purpose of this study was to provide information on log value recovery from the harvesting of steep <u>Pinus radiata</u> plantations.

3.2.1 Objective statement

The objectives of the study were:

(1) to determine if there was a difference in log value recovery for a typical harvesting operation of an intensively managed, 40 year old Pinus radiata stand on steep terrain when trees were cut into log lengths

(a) at the stump, and

(b) at a landing.

(2) to determine the effect different log manufacturers have on value recovery for the two locations above.

(3) to determine how sensitive these findings were to a range of typical log prices.

3.2.2 Hypotheses

It is hypothesised that:

(1) There is no significant difference in value recovery between marking and cutting trees into log lengths at the stump and at the landing.

(2) There is no significant difference in value recovery obtained by competent log markers for the above two locations.

(3) Neither a 20% increase, nor a 20% decrease in price paid for high-value peeler logs will alter the relationships found in hypotheses 1 and 2.

3.2.3 Scope and limitations

The primary focus of this study is to determine if there are any significant differences in value recovery when stems from Radiata pine plantations on steep terrain are manufactured into logs at the stump versus at a landing. The study will be limited by the following conditions:

(1) Stems from a single stand of 40 year old Radiata pine on steep terrain which has been pruned and thinned down to a low final crop stocking will be used. Average tree size will be about 3 cubic metres.

(2) The analysis to be carried out assumes that the study area is harvested by a cable system. (A tractor was the only equipment available to do the extraction at the time of the study.)

(3) The three log manufacturers studied each had at least 7 years experience working with logging operations.

(4) Nine log types were manufactured during the study. A wide range of product types were cut - from low value random length pulpwood up to high value fixed length pruned butt peelers.

(5) The log prices used in the analysis were current at the time the field work was carried out (March 1984).

(6) The log manufacture was carried out under a practical logging situation. The log manufacturers were not told to maximise value recovery at the expense of productivity.

3.2.4 Factors affecting value recovery decision-making

The reasons for poor value recovery are many and varied. The first of these would have to be a lack of interest by management in achieving high levels of value recovery (Twaddle, 1986a). In a single product (e.g. pulpwood) operation where volume production is of prime importance management may have little interest in value recovery - productivity and costs are the major concerns. If management is not interested then neither will the logger be.

On the other hand some logging managers would like to see incentives in logging contracts and a cost-value relationship to measure the performance of the logger that will motivate the logger to get the maximum value and volume from each hectare he harvests at the lowest costs (Shook, 1975). Pressure by management to achieve high productivity should not result in poor value recovery (Briggs, 1980).

Log manufacturing is a skill that can be learned the hard way, by trial and error, or through effective training. Some authors believe that a lack of instruction in the fundamentals that affect log manufacturing is a major reason why losses occur (Bryant, 1923; Petro, 1961).

The complexity involved in considering all of the log specifications, grading rules, and tree characteristics, combined with price differentials for logs and end products puts great pressure on the log manufacturer by posing a very difficult decision problem. Selection of the most appropriate combination of log lengths to cut from a tree is itself a difficult problem whenever the log manufacturer is confronted with even a few length choices (Briggs, 1980). Twaddle (pers. comm.)

has found in New Zealand that the more complex the log specifications the poorer the level of value recovery.

Difficult work conditions may also impair the log manufacturers' ability to make good decisions. Impairment may result from

(a) inability to see all of the tree so that all defects are identified

(b) difficulty in implementing the decision because of problems from rocks, binds, obstacles, or access

(c) the heavy physical workload.

The workload imposed by different log manufacturing locations can effect decision making and value recovery. Vik (1980) found that the human energy consumption for steep terrain tree-length cutting of Norwegian stands (mean DBH of 25 cm) where delimbing is done at the stump, was approximately 3.5 times as high as cutting full-trees at the stump followed by delimbing at the landing; 815 kJ/cu.m. and 275 kJ/cu.m. respectively. Manufacturing the stems into logs on steep terrain would undoubtedly have resulted in even higher energy consumption.

McCormick (1970) reports that human factor research indicates that decisionmaking errors increase substantially as stress is applied. Stress can be measured in terms of physical workload or in terms of the number of signal sources that a decisionmaker has to deal with in a given amount of time. Humans have the capacity to channel 40 to 50 bits of information per second and make use of 0.7 to 4 bits per second. Kudinov (1966, 1969) and Leonov (1967) found in typical Soviet production lines, that the operator of a log manufacturing station must be capable of comprehending 2.13 to 4.26 bits of knot defect information per second for conifers. They concluded that the human brain is inadequate for making good unassisted decisions at production level speeds. The log manufacturer, working in the forest, does not have to make decisions as quickly as the log manufacturer on a production line but his work environment is usually not as comfortable. He has many other things to worry about.

3.2.5 Log manufacturing at the stump versus on a landing

Stenzel, Walbridge, and Pearce (1985) state that

> The trend toward tree length and long-log skidding [in the US], where the bucking [log manufacturing] is done at a landing or millyard has popularized multi-product utilization. Bucking at the landing allows the bucker to make a more thorough examination prior to actual bucking than would have been possible if the bucking were done in the woods. The bucker is not encumbered by brush,

> jack[straws], or lays which might result in selecting a bucking point in the interest of safety or expediency instead of one based upon product dimensions.

Log manufacturing can be tough on steep, brushy country, whereas, on a large flat landing, it can be highly efficient, more effective and done more cheaply (Brown, 1958: Bruce, 1966). Small landings, on the other hand, are the bane of loggers (Conway, 1982) whether log manufacturing is carried out on them or not - room is still needed to store and sort logs even if logs are being loaded onto trucks shortly after they are extracted.

Manufacturing logs on a landing has other advantages. It is thought to be safer and easier to supervise than manufacturing at the stump (Petro, 1965; Simmons, 1979). And delimbing is already partly done by skidding or yarding (Dent, 1974; Breadon, 1983).

Improved value recovery, resulting from cutting fewer inaccurate log lengths at a landing than are cut at the stump, is often cited as one of the advantages of manufacturing logs on a landing (Dent, 1974; Breadon, 1983). Blackman (1979) described a U.S. logging operation where tree length extraction and log manufacturing at a reload station in an abandoned rock quarry was favoured because better quality control was possible. This operation found that, with better control and supervision, few peeler bolts were cut short and lost. McIntosh (1970) has found, on the other hand, that when White Spruce stems were processed on a landing in Canada 98% of the 32 foot logs produced were either too short or too long.

Twaddle (1984) has pointed out, however, that a landing is not the ideal place to manufacture logs; there are disadvantages. The log manufacturer has to make decisions while working amongst heavy equipment - log loaders, skidders, and yarders - and in coordination with the equipment operators. Since the log manufacturer is closer, at the landing, to a high-paced, production environment he can be influenced by the pressures on the other workers. Twaddle has noted examples of log manufacturers quickly cutting random length sawlogs instead of preferred lengths so that a tractor would not be held up and declining to cut short peeler bolts (2.0 m) because truck drivers did not like handling them. Twaddle (1986a) reported that the average level of value recovery obtained when logs are manufactured from stems on large landings in New Zealand is about 85% of the potential value. From six studies involving the measurement of over 4700 logs he found that 17 to 32% of all logs produced on a landing were out of specification. Dimension features, such as out-of-roundness, sweep, and branch-size, were the most common causes (Twaddle, 1986b).

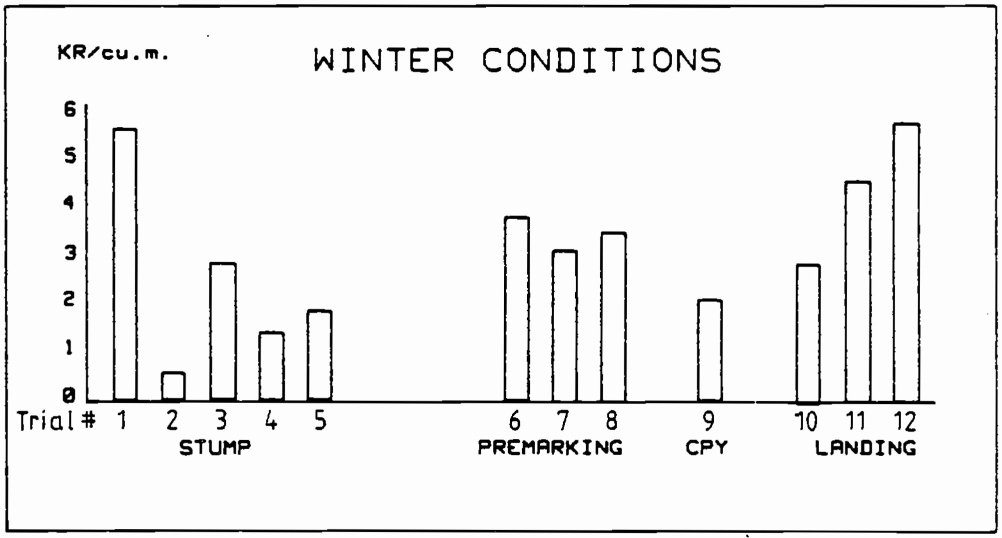
When tree-length radiata pine logs are yarded by cable systems for processing on landings in New Zealand some stem breakage occurs during extraction. Murphy and Hart (1979) have found that about 3-4% of the stems break and have estimated the value loss to be less than 2%. Most of the breakage occurs in the top portion of the tree which generally contains low value and low volume material.

Comparative value recovery studies are sparse in the forestry literature. Studies carried out in Sweden by Dahlberg (1968) showed that the differences in value recovery between alternative log manufacturing techniques and locations vary between 0.7 and 6.6 percent. He has shown that the differences are greatest for pine of great taper and least for spruce of little taper.

Probably the most comprehensive study was carried out in Norway by Landerud, Lier and Oy (1973). Their study attempted to determine the effect of harvesting season (summer or winter) and log manufacturing alternatives on value recovery. Twenty three trials were carried out in vigorous stands of good form. A total of 571 stems were manufactured into 1819 logs. Different log manufacturers were used to process about 25 stems for each trial. Four log manufacturing alternatives were investigated;

- cutting stems into log lengths at the stump (referred to as STUMP on Figure 3-1),
- marking the log lengths at the stump, then extracting the stems to roadside where the final cuts were made (PRE-MARKING),
- extracting unmarked trees to a landing where they were marked and cut into log lengths (LANDING),
- extracting tree lengths to a central processing yard where automated equipment was available to aid in the log manufacturing decision (CPY).

The basis for reporting differences in value recovery for the different log manufacturing alternatives was the difference in value per cubic metre between the actual recovery obtained by the log manufacturer (practical) and a "theoretical" value. The theoretical value was determined by the study team after careful examination of the stem and deliberation. It appears that



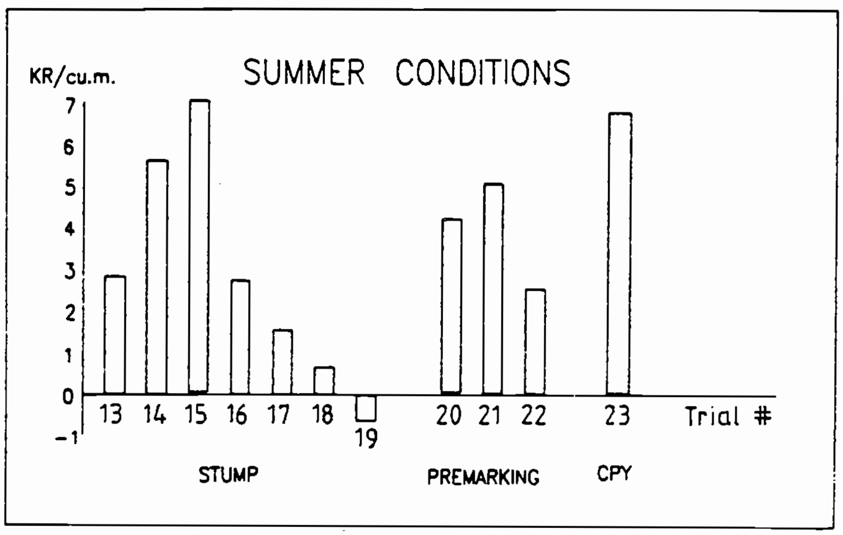


Figure 3-1 Difference in value (Norwegian Crowns) between actual and theoretical value recovery for different log manufacturing alternatives under summer and winter conditions.
Source: Landerud and others (1973).

the study team did not use one of the log-bucking optimisation algorithms to aid in arriving at a theoretical value.

Figure 3-1 is a translation of one of the figures from their paper. First of all, they found great differences in value recovery between different log manufacturers using the same alternative. For example, under summer conditions processing at the stump, one log manufacturer obtained an average recovery which was 7 Crowns per cubic metre worse than the "theoretical" value, while another log manufacturer actually achieved a recovery that was 1 Crown per cubic metre better than the "theoretical" value. (The latter result could only occur because the theoretical solution was determined without the aid of an optimisation algorithm and was also sub-optimal.)

Failure to recognise differences in quality up the stem and inaccurate length measurement were the greatest causes of lost value. There appeared to be a greater tendency to overcut the lengths on landings compared with at the stump but the variability in the data makes comparison such as this difficult.

The great variation in recovery between different people made it difficult for them to separate out the effects of the log manufacturing alternatives. For example, manufacturing at a central processing yard gave one of the worst recovery levels for summer conditions and one of the best for winter conditions. Although it appears that manufacturing pre-marked or unmarked logs on a landing in the forest gave poorer recovery than processing at the stump under winter conditions the authors say that the variability in the data precludes them from making such judgements. They do believe, however, that a 2 to 5 Crown per cubic metre improvement in value recovery could be obtained by better log manufacturing - whether it be at the stump, roadside, or landing. There is no indication in their paper of the percentage differences between the different log manufacturing alternatives.

The study above highlights the great effect the human factor can have on value recovery. If differences between log manufacturing alternatives are to be identified more control over the human element needs to be incorporated into the study design.

3.3 STUDY DESIGN AND METHODS

3.3.1 Dependent variables and sources of variation

The dependent variables used in the study were

(a) the monetary value of the trees measured in NZ$/stem

and (b) percentage value actually recovered as compared with the optimal solution as determined by the AVIS system.

Sources of variation of the dependent variables were thought to include:

(1) tree size - big trees tend to be worth more than small trees. Tree size, as indicated by diameter breast height over bark, was treated as an independent variable in the study.

(2) stand variation - the age at time of harvest and the silvicultural treatment that different trees have received prior to harvest, in terms of fertilisation, weed release, pre-commercial and commercial thinning, and pruning effect their physical form and quality. Physical form and quality in turn affect the value of trees. The variation in silvicultural treatments that stands have received in New Zealand is large. Rather than face the high cost of sampling from a wide range of stand

conditions it was decided that a single stand, representative of future stands to be harvested from steep terrain, should be selected.

(3) site variation - to minimise the effect that site variation (aspect, soil moisture, soil fertility) has on tree form and value the study was designed so that all trees came from a single, uniform felling site.

(4) log types produced - the number and types of logs manufactured varies from one logging operation to another. Some operations produce a single product (e.g. pulpwood), others produce many products ranging from pulpwood, through sawlog grades, to veneer logs. Most New Zealand logging operations cut multi-products. The logging operation selected for this study used a typical multi-product set of log types.

(5) log prices - market conditions affect the value that can be recovered from trees. Log prices in the Bay of Plenty region of New Zealand, March 1984, were selected for use in the study. The study was designed, however, to test the sensitivity of log value recovery to different log price structures.

(6) log manufacturing personnel - it has been found in many industries that the human factor plays a very important role in determining profitability, generally through the effect on productivity. It was expected that different people might have different abilities to

recover the potential value from given trees. Log manufacturing personnel were, therefore, treated as an independent variable in the study design. Variation in the ability to recover potential value could result from differences in

(a) the skill the log manufacturer has gained either through experience or training

(b) the attitude the log manufacturer has towards optimising stem value

(c) the knowledge the log manufacturer has on the importance of maximising value to the profitability of the operation

(d) perceptual abilities the log manufacturer has which might allow him to "measure" diameters and branch sizes without aids

(e) the level of risk the log manufacturer is prepared to take to cut the most value out of a stem under dangerous circumstances.

(7) log manufacturing location - it was thought that the differences in working conditions at the stump site and the landing site would effect the amount of stem value recovered. Log manufacturing location was treated as one of the major independent variables in the study design. The size of landing and number and arrangement of log sorts on the landing could effect value recovery. The landing in this study was typical of landings on steep

terrain where space for landing construction is limited by New Zealand standards.

3.3.2 Statistical design

One of the major problems to overcome in the statistical design of this study was the variability that is usually found in individual trees with regard to tree form, quality, size, and breakage. At least two ways exist to deal with this variability:

(1) take very large samples. The high cost of carrying out log value recovery studies prevented designing for a large sample size.

(2) use "matched" pairs of trees for the two log manufacturing locations. To obtain the required matched pairs it was decided that felled trees should be tagged, delimbed, and then marked for cutting into log lengths at the stump site. The saw-cuts would <u>not</u> however be made at the stump site. Other than the identification tag all marks would then be removed from each tree. After all trees were felled they would be extracted to a landing where they would be re-marked and finally manufactured into logs. A comparison of recovery at both the stump and landing site could then be obtained for the same trees.

Previous experience working with value recovery data from similar types of stands indicated that a sample size of about 200 trees would be more than adequate for this type of study (A.A. Twaddle, pers. comm.). This would allow for stems not extracted during the course of the study, lost tags, and broken logs.

3.3.3 Study methods

3.3.3.1 Stand details

A site was selected in Compartment 18 of Whakarewarewa State Forest Park. The stand had been silviculturally tended but not to the intensity nor timing of the currently accepted "optimal" regime. Currently accepted regimes usually specify that all pruning and thinning treatments be completed by the times the trees are 10 to 12 years old. I believe, however, that the belated treatment given to the stand may be typical of future steep country plantations. Details obtained from stand inventory records are presented in Table 3-1.

The study area was relatively steep with slopes averaging 25 degrees (45%). It had some extraction tracks remaining from the previous production thinning.

Table 3-1. Stand details.

Location	Compartment 18, Whakarewarewa S.F.P.
Establishment	Natural regeneration following logging. Year of establishment taken as 1944.
Silvicultural history	1959 - high pruned 0 to 6 m. 1963 - ultra-high pruned 6 to 12 m. 1963 - production thinned to 200 stems per hectare. (spha)
Stocking	192 spha.
Mean tree volume	3.3 (cubic metres)
Mean diameter breast height over bark	55 cm
Total live volume	633 cu.m./ha.

3.3.3.2 Harvesting system

The terrain classification for the area, using the FRI terrain classification system (Terlesk, 1983), was 5:2:4 indicating a cable system as the most suitable extraction system. No cable yarder was available for use in the forest, however. The area was, therefore, contour-tracked for downhill extraction by a contractor-owned and operated Komatsu D60 bulldozer. Although the area was able to be logged by a tractor, it was limited to use in dry conditions and would not have been able to be in production all year round. Figures 3-2 and 3-3 show a topographic map and oblique aerial photo of the study site and landing. The landing size (0.16 ha) and hot-

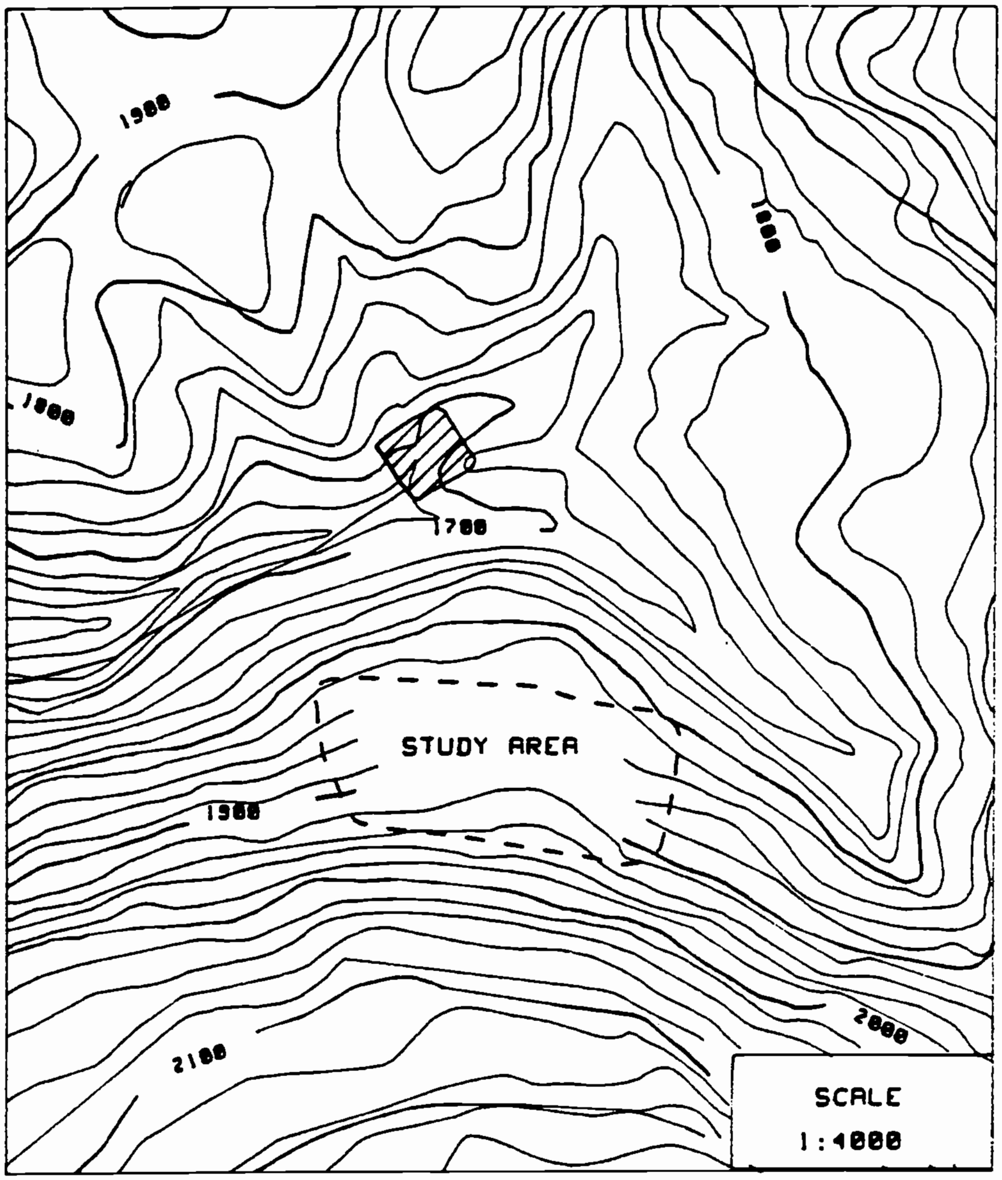


Figure 3-2 Topographic map of study area and landing (hatched).

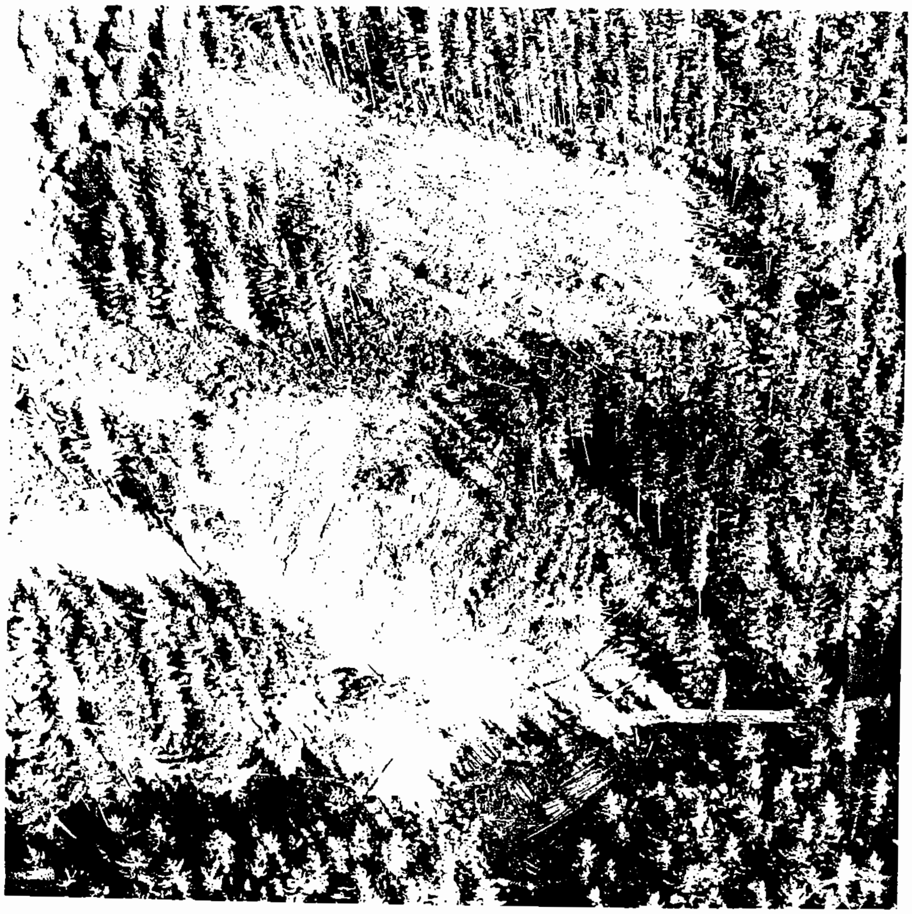


Figure 3-3 Oblique view of study area (top) and landing with log decks (bottom). Note that this figure is upside down compared to Figure 3-2.

decking situation were typical of current yarder operations in New Zealand radiata pine plantations where landing construction is difficult and expensive.

The approximately 2 hectare portion of the stand included in the study was clear-felled across slope prior to extraction in late summer of 1984. The trees were directionally felled across slope to make delimbing and marking of stems for cutting into log lengths easier for the log manufacturer. Felling breakage was reduced compared with downhill felling but the across-slope felling created some problems in breaking out the loads by the tractor. The tractor did not have an integral arch or utilise a towed logging arch. Greater breakage occurred than normally would have been found with a cable yarding system where lift can be provided to raise stems clear of other stems and stumps. Some stems had to be cut in half to facilitate their break-out. About a quarter of the stems either had to be cut or were broken, an abnormally high proportion. These were removed from the data base.

The logging crew normally consisted of a faller, two people who hook on tree-length logs, a tractor operator, two people who unhooked and manufactured logs at the landing, and a loader operator. As stated earlier in this chapter log manufacturing is normally done on a large landing in New Zealand.

During the study period three members of the contractor's crew were replaced by New Zealand Logging Industry Research Association (LIRA) and New Zealand Forest Service employees. Across slope felling (or directional felling) is relatively new to New Zealand. A LIRA employee, who was skilled in this technique, assisted us during the study. The log manufacturers used in the study were not a sample of the harvesting workforce. The New Zealand Forest Service provided log manufacturers who were thought to be skilled in recognising differences in log grades and in obtaining the most possible value from given stems.

An International Hough 60 rubber-tyred front-end loader carried out all log sorting and truck loading on the landing.

3.3.3.3 Log manufacturers' experience

Three people were used to mark and manufacture logs during the study period. The level of value recovery found for these three people was similar to that reported in other value recovery studies in New Zealand. To make things easier for the reader and for myself I will use their first names - Solly, Dick, and Jim - rather than refer to them throughout the rest of this chapter with some numerical or letter code. All three people marked stems at the stump on the hillside. Only Solly and Dick marked and manufactured logs on the landing. It was recognised that Jim had poorer ability to recover value.

Based on the number of high value peeler logs cut Solly was considered by the Logging Planning Officer for Whakarewarewa S.F.P. to be the best person they had on the forest for his ability to recognise and recover value in stems. He normally manufactured logs on a landing for one of the Forest Service's own crews. Solly had 9 years experience working with a silvicultural crew and had then gone through 3 months learning with a training logging crew. He had then spent four years with logging crews operating in larch, Douglas fir, and Radiata pine plantations. Two of those four years were manufacturing logs on the landing.

Dick was a logging supervisor for the forest. He supervised the day to day activities of the contractor and government logging crews. Dick was also recognised by the Logging Planning Officer of Whakarewarewa State Forest Park for his ability to distinguish between various log grades and recover value from stems manufactured on a landing. Dick started his forestry career with a 2 year course, which included six months of logging experience, at the Kaingaroa Woodsman School. He then spent eighteen months working with non-harvesting functions before going through another eighteen months training programme with tractor, rubber-tyred skidder, and yarder operations. He then shifted to Whakarewarewa S.F.P.. He had been a logging trainer/supervisor for four years prior to the study.

Jim was a logging trainer for the State Forest Park and an international competitor in logging sports events. The Logging Planning Officer believed that Jim was very experienced in organising harvesting activities and in felling and delimbing techniques. Jim had, by far, the most harvesting experience of the three log manufacturers. He was, however, considered, by the Logging Planning Officer, to be a poor performer when it came to recovering value.

3.3.3.4 Field procedure

Two hundred and forty trees were selected and numbered for felling in the study area. As each tree was felled it was delimbed, topped, and then measured and marked for cutting into log lengths by whichever log manufacturer was available on the day that data was being gathered. There was no attempt to assign particular trees to particular log manufacturers. The log manufacturer was expected to mark each stem into the log types and lengths which he thought would optimise overall stem value. Each tree was then tagged with permolat strips on the butt and the tree number painted in several places along the stem.

AVIS cruise data on each stem (see Chapter 2) was then collected by a three person study team. The methods for collecting this data are described by Geerts and Twaddle (1985) and Threadgill and Twaddle (1986). The data included:

- tree tag number
- piece number if the tree broke into more than one merchantible piece
- stump height
- diameter breast height over bark
- occurrence and type of butt-damage
- piece length
- defect codes up the stem
- quality codes up the stem
- quality lengths up the stem
- stem taper
- log lengths and types, including waste, marked to be cut out of each stem
- log manufacturer's name

The stem was assessed on quality features, i.e. out of roundness, sweep, branch size, surface defects, and nodal swelling, which were independent of log dimensions. Assessment of the stem on the ground meant that changes in stem quality could be detected accurately along the whole length of the stem. Felled trees seldom lie in contact with the ground along their whole length but rather are suspended above ground by other trees, ground irregularities, branches, and undergrowth. Thus for much of their length stem quality could be assessed having viewed all sides. When using the AVIS system the position of changes in stem quality were measured to the nearest decimetre.

Rather than use a general volume or taper equation for the calculation of individual volumes, sectional measurements were made on each stem allowing a more accurate measurement of individual tree volume. Over-bark diameters were measured at the butt and successive fixed intervals along the stem. The intervals were either two, three, or four metres depending on stem length and variation in taper. The AVIS system uses a general underbark equation to estimate underbark diameters for the measured overbark diameters.

After gathering the cruise data on each stem, the marks placed by the log manufacturer to indicate the lengths and types of each log were removed. The stems were not cut into log lengths at the stump.

After all trees had been felled, marked, and cruised extraction in tree-length form to the landing began. Not all stems arriving at the landing were used in the data analysis for this study; missing tags, breakage, and trees from outside the study site were the main reasons for not using all stems. Once a tractor load of stems arrived on the landing the log manufacturer delimbed any branches not removed at the stump, marked the stems for conversion into logs, and then cut the stems into the various product types. The study crew would then measure the lengths of each log and record the type and sequence up the stem. The name of the log manufacturer for each stem was also recorded. Permolat tags, stapled to the butts of the trees, helped identify each of the stems.

Table 3-2 Log manufacturer statistics*

Stump:		
Log manufacturer's name	Number of stems	Number of logs
Solly	78	258
Dick	22	75
Jim	43	146
Sum	143	479
Landing:		
Solly	93	330
Dick	50	183
Sum	143	513

* Only stems used in the analysis are recorded in this table.

As mentioned earlier, there was no attempt to have a particular stem marked for cutting at the landing by the same person as did the marking at the stump; whichever log manufacturer was available for use on a particular day during the study period was used. Matching stems with people would have been difficult to supervise and would have removed some of the "production pressure" from the log manufacturer. Nevertheless, for one log manufacturer, Solly, it was possible to find a matched set of 52 stems. No bias was expected in the results due to markers remembering their earlier decisions; marks were removed at the stump and at least a week passed between the initial marking of any given stem at the stump and the final marking at the landing. Table 3-2 shows the number of stems, and number of logs marked for cutting by each of the log manufacturers.

3.3.3.5 Log specifications, qualities, and prices

Ten log types were to be marked and cut during the study. Table 3-3 gives the specifications for each of these log types. Three main log types were cut over the study period. These were peeler logs, sawlogs, and pulpwood. The peeler logs included three grades; butt, internode, and construction and industrial (C & I). The sawlog grade had three divisions; a premium on 12.3 m logs, shorts with no major defects, and longs which were allowed one major defect.

A description of the qualities allowed in each of the log types is presented in Table 3-4. Peeler logs had the usual restrictions on out-of-roundness, sweep, and surface defects. The main differences in quality amongst the peeler logs were that the butt grade could only be produced from the first 7m of the stems so as to maximise the amount of clearwood, internode peelers could contain one whorl of branches within one metre from the end of 5.3 m logs, and C & I peelers had no restrictions on branches provided they were below 7 cm in size.

With sawlog grade the main difference in quality was that logs greater than 6 m in length were permitted one major defect. Maximum knot size was large at 25 cm and some felling defects were also permitted.

Few restrictions were imposed on pulpwood quality logs.

Table 3-3 Log specifications

Log type	Length (m)		Diameter (cm)	Acceptable quality codes
	Min.	Max.	Small End Min.	
Peelers:				
Short butt	2.7	2.7	35	B
Long butt	5.3	5.3	35	B
Short internodal	2.0	2.0	35	BI
Long internodal	5.3	5.3	35	BIM
C & I	5.3	5.3	35	BIMC
Sawlogs:				
Short random	3.6	5.9	15	BIMCS
Long random	6.0	13.3	15	BIMCSD
Fixed length	12.3	12.3	15	BIMCSD
Pulp:	3.2	13.3	10	BIMCSDX
Waste	-	-	-	BIMCSDXW

Table 3-4 Quality codes

Quality code	Description
B	Must be pruned. Must be cylindrical, i.e. not out of round by more than 10%. Sweep - maximum allowed is s.e.d. divided by 4 per 3.7m length. No kinks, fluting, or slit scars allowed. Must be free of drawwood, splitting, slabbing, or thinning damage (> 3cm deep). Only found between 0 and 7 m in height from base of tree. Off-centre pith not permitted, i.e., must be less than one third radius from true centre.
I	Must be pruned. Must be cylindrical, i.e. not out of round by more than 10%. Sweep - maximum allowed is s.e.d. divided by 4 per 3.7m length. No kinks, fluting, or slit scars allowed. Must be free of splitting, slabbing, or thinning damage (> 3cm deep). Only found between 7 and 12 m in height from base of tree. Off-centre pith not permitted, i.e., must be less than one third radius from true centre.
M	Same as "I" except that branches are permitted. Only occurs less than 1 m from the end of an "I" coded zone.

Table 3-4 Quality codes. (continued)

C	Must be cylindrical, i.e. not out of round by more than 10%. Sweep - maximum allowed is s.e.d. divided by 4 per 3.7m length. No kinks, fluting, or slit scars allowed. Must be free of drawwood, splitting, slabbing, or thinning damage (> 3cm deep). Knot size - maximum of 7 cm permitted. Off-centre pith not permitted, i.e., must be less than one third radius from true centre.
S	Maximum sweep for logs of length < 4.0 m = s.e.d./4 per 3.7 m length. 4.0-5.9m = s.e.d./2 " " ". > 6.0 m = s.e.d. " " ". Maximum knot size is 25 cm. Splits, drawwood, and slabbing up to 15 cm. allowed. Maximum nodal swelling for s.e.d.'s < 35 cm = 8 cm > 35 cm = no restriction.
D	Same as "D" except that a single major defect less than 2 m long is permitted. E.g. chamfer cut, or kink.
X	Sound dead wood allowed. No soft rot allowed. All logs not suitable for above quality codes.
W	Anything that does not meet above quality standards is waste quality.

Table 3-5 shows the prices paid for the different log grades during the study period; hereafter referred to as the current prices. It also shows two other price schedules used to test the sensitivity of the recovery levels to changes in price of the higher valued log grades. Prices of the peeler log types were reduced by approximately 20% (pessimistic) and increased by approximately 20% (optimistic). Sawlog and pulpwood prices were held constant. The basis for the plus or minus 20% range in peeler prices is a best "guestimate" provided by an economist at the New Zealand Forest Research Institute (Katz, pers. comm.).

Table 3-5 Log price schedules

Log type	Prices (NZ$/cu.m. under bark)		
	Pessimistic	Current	Optimistic
Long butt peeler	66.00	82.50	99.00
Short butt peeler	62.80	78.50	94.20
Long int. peeler	50.00	62.50	75.00
Short int. peeler	46.80	58.50	70.20
C & I peeler	40.00	50.00	60.00
Fixed sawlog	34.00	34.00	34.00
Long sawlog	32.00	32.00	32.00
Short sawlog	32.00	32.00	32.00
Pulp	14.00	14.00	14.00
Waste	0.00	0.00	0.00

3.4 DATA ANALYSIS PROCEDURES

3.4.1 Use of AVIS system

The AVIS computer program was used to:

(1) calculate the optimal value that could be obtained from each stem for the three price schedules,

(2) determine the volumes of each of the log types marked for cutting by the log manufacturers at the stump and at the landing,

(3) identify the occurrence and reasons for logs not meeting specifications.

The dynamic programming optimisation algorithm used in the AVIS program and examples of the computer output were presented in Chapter 2. and so will not be discussed further here. The reader is referred to the AVIS User's Guide (Threadgill and Twaddle, 1986) for a fuller understanding of this data analysis procedure.

3.4.2 Calculation of value recovery

About a third of the logs (by volume) did not meet permitted specifications. The AVIS computer program identifies such logs but does not adequately deal with them for the purposes of this study. A set of rules for determining the value of logs, which did not meet specification, were developed. Table 3-6 shows the value reduction decision rules used for logs not meeting specification (Twaddle 1984b). These rules were incorporated in a template built for a spreadsheet program (SYMPHONY) on a personal computer. If a log did not meet specification on more than one account the rule that would result in it having the lowest value was used. For example, if a log marked as a fixed length sawlog contained pulp quality and was 15 cm too long, use of the quality decision rule would result in a lower value than the length decision rule; the quality decision rule would be the one used.

The spreadsheet was used to calculate value recovery for each stem, both in New Zealand dollars and as a percentage of the optimal AVIS solution. The spreadsheet program also proved to be an invaluable aid in data and file manipulation, and data analysis. Sorting of data by log-manufacturer and location, and calculation of basic summary and test statistics were done with the spreadsheet.

Table 3-6 Value reduction decision rules for logs not meeting specification.

Log type		Reduction rule
Does not meet quality specifications:		
Butt peelers:	2.7 m	Reduce value to $ 0.00
	5.3 m	If unacceptable quality code covers less than half peeler volume reduce value by 50%. If it covers more than half of peeler volume reduce to value of lowest code.
Internode peelers:	2.0 m	As for butt peelers (2.7m)
	5.3 m	As for butt peelers (5.3m)
C & I peelers	5.3 m	As for butt peelers (5.3m)
Sawlogs		Reduce to the value of the lowest code.
Pulp		Reduce to waste.
Does not meet minimum small end diameter specifications:		
All peelers	5.3 m	If > 1 cm reduce value by 50%.
	2.0 & 2.7 m	If > 1 cm reduce to waste.
Sawlogs		If > 2 cm reduce value to pulpwood.
Pulpwood		If > 3 cm reduce value to waste.
Does not meet length specifications:		
All peelers		If > 5 cm reduce value by 50%.
Sawlogs - random		If > 20 cm reduce value to pulpwood.
- fixed length		If ± 10cm reduce to random sawlog value.
Pulpwood		If > 30 cm reduce to waste.

3.4.3 Statistical analysis

3.4.3.1 Comparison of a Family of Regression Lines

Much of the statistical analysis was carried out on a personal computer using files transferred from the spreadsheets to a program called Number Cruncher Statistical System (NCSS). The main analysis technique used is called Comparison of a Family of Regression Lines (or Giant Size Regression, GSR). Since it was such an important component of the analysis it will be outlined below. A detailed discussion of the technique can be found in Cunia (1973).

The technique makes use of indicator (or dummy) variables in multiple regression analysis. There are several approaches to using indicator variables (Neter and others, 1983). The most common approach requires n-1 indicator variables for n classes of observation and has a separate intercept (B0). The approach used in the giant size regression technique requires n indicator variables for n classes of observation and has no separate intercept. The regression model for this technique would be

$$Y = \sum_{i} \sum_{j} B_{ij} X_{ij} + \epsilon$$

where i indexes the "class" of observations and j indexes the independent variable. More specifically, as an example, one of the regression models used in the statistical analysis for this study was:

$$\hat{Y} = \hat{B}_{11}X_{11} + \hat{B}_{12}X_{12} + \hat{B}_{21}X_{21} + \hat{B}_{22}X_{22} + \hat{B}_{31}X_{31} +$$

$$\hat{B}_{32}X_{32} + \hat{B}_{41}X_{41} + \hat{B}_{42}X_{42} + \hat{B}_{51}X_{51} + \hat{B}_{52}X_{52}$$

where $\hat{Y}$ = Percentage value recovery.

X_{11} = 1 if manufacturer = Solly, and location = Stump, or 0 otherwise.

X_{12} = DBH if Solly and Stump, or 0 otherwise.

X_{21} = 1 if Solly and Landing, or 0 otherwise.

X_{22} = DBH if Solly and Landing, or 0 otherwise.

X_{31} = 1 if Dick and Stump, or 0 otherwise.

X_{32} = DBH if Dick and Stump, or 0 otherwise.

X_{41} = 1 if Dick and Landing, or 0 otherwise.

X_{42} = DBH if Dick and Landing, or 0 otherwise.

X_{51} = 1 if Jim and Stump, or 0 otherwise.

X_{52} = DBH if Jim and Stump, or 0 otherwise.

For the above example, five regressions could have been obtained, one for each class of observations. To test assumptions about common slopes and intercepts it is easier, however, to use a full model (GSR model) to compare against a specific reduced model. It can be shown that the coefficients in the GSR will always be numerically equivalent to those in the individual class regression functions.

The ANOVA table from the GSR model provides some of the information required for common slope and intercept tests. (As an aside the F and R^2 statistics reported by many regression packages, including NCSS, for this type of model are erroneously high; the sum of squares normally associated with the intercept (B0) is incorporated into the regression sum of squares - the numerator for both the F and R^2 statistics.)

To test for common slopes (DBH) between individual class regression functions the following null and alternative hypotheses are formed:

$$H_0 : B_{i2} = B_2^*$$

H_1 : Not all slopes equal, i.e., at least one

unique slope

For the example given above, the reduced model used to test this hypothesis would be:

$$\hat{Y} = \hat{B}_{11} X_{11} + \hat{B}_{21} X_{21} + \hat{B}_{31} X_{31} + \hat{B}_{41} X_{41} + \hat{B}_{51} X_{51} + \hat{B}^{*}_{2} X^{*}_{2}$$

where Y and B_{ij} are as above, and X^{*}_{2} = DBH.

To test for common slopes the following is computed:

$$\hat{F} = \frac{SSR_1 - SSR_2}{df_{r1} - df_{r2}} \Big/ \frac{SSE_1}{df_{e1}}$$

where SSR_1 and SSR_2 are the regression sum of squares for the full and reduced models respectively, df_{r1} and df_{r2} are the degrees of freedom associated with the full and reduced models, SSE_1 is the error sum of squares for the full model, and df_{e1} is the degrees of freedom associated with the error of the full model.

If $\hat{F}$ does not exceed a critical F value with (df_{r1} - df_{r2}) and df_{e1} degrees of freedom we can say there is no statistical evidence to suggest that the true slopes of the lines are sufficiently different from each other to warrant estimation of individual slopes.

If a common slope is found then a hypothesis is formed so that a test for a common intercept can be carried out. The hypothesis would be:

H_0 : $B_{i1} = B_1^*$

H_1 : Not all intercepts are equal, i.e. at least two intercepts are significantly different.

The super-reduced model would then become:

$$\hat{Y} = \hat{B}_1^* X_1^* + \hat{B}_2^* X_2^*$$

where $X_1^* = 1$ for all classes.

An F statistic is again computed as follows:

$$\hat{F} = \frac{SSR_2 - SSR_3}{df_{r2} - df_{r3}} \bigg/ \frac{SSE_2}{df_{e2}}$$

Statistics subscripted with a 2 relate to the reduced model, and with a 3 to the super-reduced model.

If the calculated F value is greater than the critical F value then there is statistical evidence that at least one pair of regression lines does not have a common intercept. When that occurs, as it did frequently in this study, the next step is to determine which intercepts are different. One can start with any "pair". For example, to compare Solly manufacturing logs at the stump and at the landing the following new model would be formed:

$$\hat{Y} = \hat{B}_{(12)1} X_{(12)1} + \hat{B}_{31} X_{31} + \hat{B}_{41} X_{41} + \hat{B}_{51} X_{51} + \hat{B}^{*}_{2} X^{*}_{2}$$

where $X_{(12)1}$ = 1 if Solly; or 0 otherwise.

The F statistic calculated in this case would be:

$$\hat{F} = \frac{SSR_2 - SSR_4}{df_{r2} - df_{r4}} \bigg/ \frac{SSE_2}{df_{e2}}$$

The sums of squares and degrees of freedom are from the reduced model and the new model.

All pairs are tested in a similiar fashion to above.

Over 100 regression models were built and compared for the three price schedules, three log manufacturers, two manufacturing locations, and two dependent variables.

3.4.3.2 Selection of dependent variables and model assumptions

Linear regression models are based on the following assumptions:

(1) There is a linear relationship between the dependent and independent variables.

(2) The variance about the regression line is constant.

(3) The residuals are uncorrelated.

(4) The residuals are normally distributed with mean zero.

In selecting dependent variables and in building the regression models it was my aim to satisfy as many of these assumptions as possible. Sometimes an improvement in one assumption caused a problem with other assumptions or the utility of the model, however.

Diameter breast height is probably the most commonly gathered tree characteristic. It was the independent variable used to differentiate tree size in this study. The relationship between stem value, measured in dollar terms, and diameter breast height is curvelinear. To linearise the value/DBH relationship two approaches were taken

(1) the dependent variable was transformed by taking the logarithm (base 10) of value (LOGVAL).

(2) a new variable, percentage value recovery, was formed (%REC).

Both these transformations also helped to meet the model assumption of constant variance. Big trees have more inherent variability than small trees with regards to value; for example a half cubic metre tree might have a $43 range in value from $7 (if it was all pulp) to $50 (if it was all peeler), whereas a four cubic metre tree with the same quality features would have a $344 range in possible value. Taking the logarithm of value or expressing it as a percentage of the optimal AVIS solution reduced a lot of the variability in the variance. Neter, Wasserman, and Kutner (1983) recommend the logarithmic transformation in particular to deal with non-linear relationships and non-constant variance.

I could not fully test the model assumption that the error terms were uncorrelated. Although plots of the residuals lagged one observation indicated a random pattern this was not a valid test. All of the data had been ordered by increasing tree number. The time relationship between tree number (and thus DBH) and residuals is not available now. I can only assume that the models built meet this assumption.

I was also unable to find transformations that would produce models with normally distributed residuals. Chi-squared tests (Mason, 1970) for both logarithmic value (LOGVAL)/diameter breast height relationships and percent recovery (%REC)/ diameter breast height relationships indicated that the residuals were not normally distributed. The residual distributions were skewed to the left and truncated to the right. This follows the same pattern as the dependent variables. Most of the data was grouped around the 60 to 90% recovery, with a few trees with recovery percentages in the 0 to 10% range and a few above 90% recovery. Since 100% is the upper limit on percent recovery the distribution is truncated to the right. I had no basis for deleting low recovery values so they remained in the data pool.

Transformations that tended to bring the residuals closer to a normal distribution also tended to reduce the F and R^2 statistics for the models. I, therefore, decided to use the logarithmic and percent recovery transformations, recognise that one of the model assumptions had not been met, and be aware that some of the test statistics generated should be dealt with cautiously.

3.4.3.3 Significance level testing

It is a common practice for researchers to test and report significance levels at the .05 or .01 level. Freedman and others, (1980) relate that the .05 and .01 levels were "born" in the pre-computer era and soon acquired a mystical life of their own. They state that there is no sharp dividing line between probable and improbable results and recommend that P values be reported as well as the words "not significant", or "significant".

The level of significance one should test at should reflect the consequences of making a false conclusion. For example, the test of a hypothesis which could result in the loss of many lives should be tested at a lower level of significance than one which might result in the loss of a few dollars. The difference in mean value recovered at the stump versus on a landing ranged to as high as $10 per tree. If we say there is no significant difference at the .05 level the highest additional expected loss per tree, from making an incorrect decision, would be about 50 cents ($10.00 x 0.05). If we raise the significance level to 0.10 the additional expected loss per tree would rise to $1. An increase in expected loss of 50 cents (or about 0.35% of total recovery). A researcher or manager would have to decide the level of cost he would be prepared to accept from making an incorrect decision. In this chapter I have reported the P values at which the test statistic would become significant. I generally classed a test statistic as being significant if it exceeded the 0.05 to 0.10 level.

3.5 RESULTS AND DISCUSSION

3.5.1 Basic recovery statistics

Basic recovery statistics for the three price schedules are presented in Tables 3-7 and 3-8. Figure 3-4 shows value loss, measured as a percentage of the optimal solution, for the "Current" price schedule only. The two tables show that value recovery, in both dollar and percentage terms, decreases as higher value is attached to the premium log grades. The mean diameter of the sample of trees processed by each of the log manufacturers is also shown in Tables 3-7 and 3-8. Although Dick appears to have recovered a similar level of value (in dollars) to Solly the trees processed by him were about 5 cm larger in diameter. On average Dick's larger trees were worth about $12.50 more than Solly's trees. The lower value recovery by Dick is reflected in the percentage figures in Table 3-8.

The large standard deviations for value recovery, resulting partly from variability in tree size and quality characteristics, make it difficult to infer from these basic statistics if there are differences between log manufacturing personnel and locations. It can be seen however that value losses were large with overall recovery being in the 70 to 80% range.

(3) to determine the sensitivity of the costs to changes in the assumptions required to carry out the analyses, and

(4) to identify deficiencies in the data base used for the system analyses.

The number of logging systems that could be evaluated for this study is infinite when one considers the possible combinations of stand conditions, yarders, loaders, manpower structure, bucking patterns, log manufacturing location, trucking haul distances, central processing yard size, and so on. This study will be restricted, however, to examining only a few combinations of these. Figure 5-2 shows the broad systems to be analysed. Further description of individual components of each system can be found in sections 5.7 and Appendix B. All analysis will be carried out using stand and piece size data derived from the log value recovery study described in Chapter 3.

The specific hypothesis to be tested by this study is:

There is no significant difference in total stump-to-milldoor system costs when logs are manufactured into their final form at

(i) the stump,

(ii) the landing, or

(iii) a central processing yard.

5.3 EXPERIMENTAL DESIGN

To reiterate what was stated in section 5.2, the main objective of this study was to see if there were significant differences in steep country harvesting system costs when logs were manufactured into their final form at one of three locations; at the stump, on a landing, or at a central processing yard. It was thought that the results might be sensitive to the size and type of yarder used to extract timber from the harvest unit. A two-factorial, randomised block experimental design was selected for the study (Peterson, 1985). The two factors in the design would be log manufacturing location and yarder type. Different harvesting units would represent the blocking (or replication) feature of the design. Simulation was considered to be the best approach for evaluating costs for the various harvesting systems (see section 5.4).

The three yarder types used in the analysis are discussed in more detail in Appendix B. They are:

- a Madill 009 rigged as a Grabinski skyline system,
- a Madill 071 rigged as a slack skyline system, and
- a Washington 88 rigged as running skyline system.

The Madill 009 is the most common yarder in New Zealand and is frequently rigged as a Grabinski system.

It is a 2-drum, 335 kW yarder mounted on a rubber-tyred or tracked undercarriage.

There are only a few Madill 071 yarders in the country. They are rigged in a range of configurations. The Madill 071 is a 4-drum, 215 kW yarder mounted on a tracked undercarriage.

There are only two Washington 88 yarders in New Zealand. They are used as running skyline systems. The Washington 88 is a 3-drum mechanical interlocked yarder mounted on a tracked undercarriage. It is powered by a 230 kW motor.

It was decided to include six log manufacturing patterns in the experimental design; three at the stump, one at the landing, and two at a central processing yard. Short descriptions of these patterns follows:

(1) AVIS optimal - this bucking pattern assumes that the faller has a handheld computer with him at the stump, which suggests the optimal way to buck the stem to get the most value out of it. The distribution of logs generated by the AVIS program as part of the output from the study reported in Chapter 3 represented the "AVIS optimal" pattern. The log distribution was used in the analysis.

(2) Solly - in Chapter 3 it was reported that there was no significant difference in value recovered by

Solly (the best log manufacturer studied) at the stump versus on a landing. The distribution of logs generated by Solly was used as a distinctive bucking pattern.

(3) Solly, Dick, and Jim - the three log manufacturers studied and reported in Chapter 3 could be classified as representative of a broad cross-section of log manufacturers in New Zealand. All logs generated during log manufacturing at the stump by these three workers were lumped into a single log distribution as a representative bucking pattern.

(4) Tree-length - the tree-lengths extracted to the landing during the value recovery study reported in Chapter 3 were representative of the tree-length bucking pattern. Trees were processed into logs on the landing.

(5) Fixed 12.6 m. - several bucking patterns that might be applicable to final manufacturing of logs at a central processing yard were described in Chapter 4. One of these was cutting stems into fixed lengths of 12.6 metres at the stump. The logs from the AVIS output for the value recovery analysis were used to generate a representative log distribution for this cutting pattern.

(6) Butt 12.6 m. - a bucking pattern not considered in Chapter 4 was to cut a 12.6 metre butt log from each stem at the stump. The average piece size would be smaller than for tree-length extraction and a large

landing would probably not be required. The AVIS output used to generate the Fixed 12.6 m. bucking pattern was modified to represent this bucking pattern.

Four harvest units were selected for replication as blocks in the design; two harvest units were located on U.S. Forest Service land in western Oregon, and two were located in Whakarewarewa State Forest Park, New Zealand. The harvest units were of different size, shape, and terrain. Figures 5-3, 5-4, 5-5, and 5-6 show the portions of the topographical maps used to generate the digital terrain models on which the harvest units were located. The harvest units were named, and will be referred to hereafter in this chapter, as USA1, USA2, NZ1, and NZ2. All material trucked was less than 14m in length.

The experimental design was a complete factorial design, that is, all combinations of treatments were replicated on each block. Each simulation run represented a combination of one yarder, one bucking pattern, and one harvest unit. Several simulation runs were completed for each combination for reasons described in the next section. A total of 72 lots (3 machines X 6 bucking patterns X 4 harvest units) of simulations were carried out for the analysis.

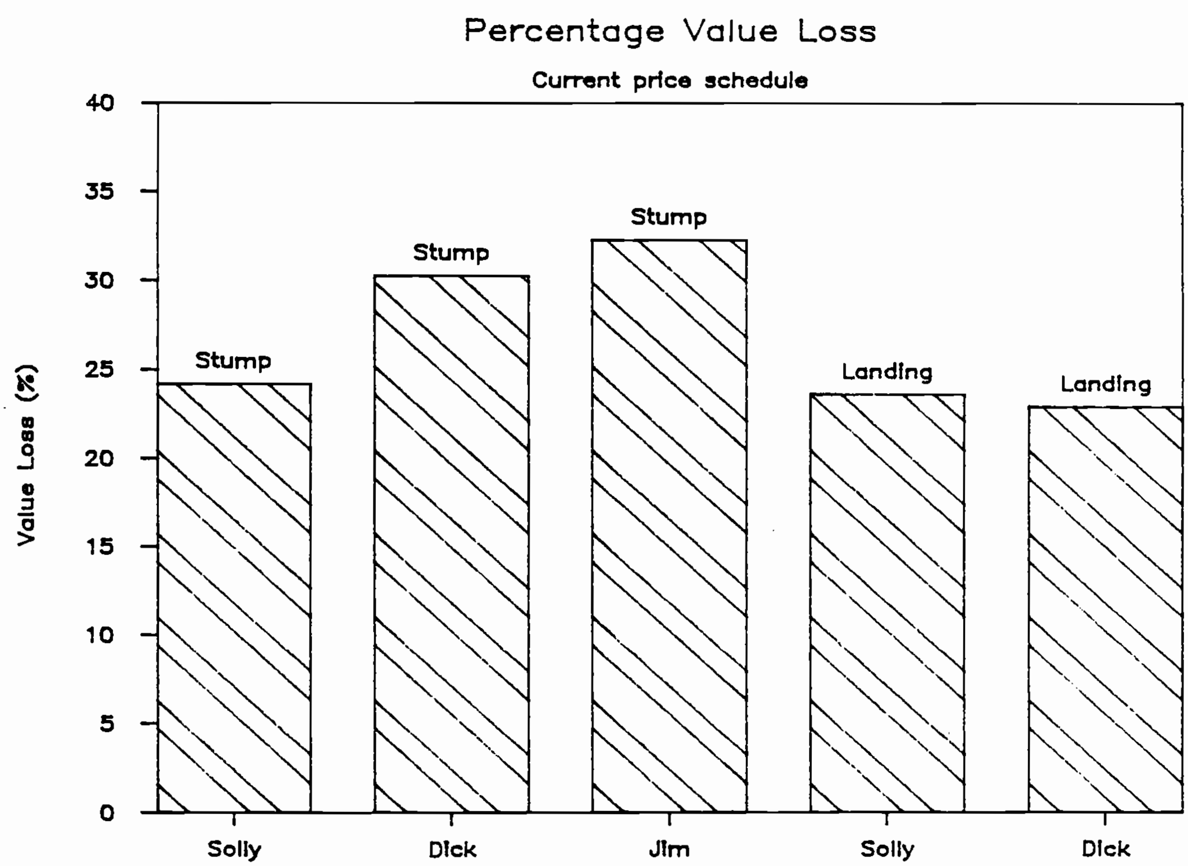


Figure 3-4 Average value loss for current price schedule.

Table 3-7 Value recovery statistics - New Zealand Dollars

Location	Log maker	DBH (cm)	Price Schedule Pessimistic	Current	Optimistic
Stump:					
	Solly	53.0	100.46	110.90	121.35
		(13.2)	(67.86)	(79.50)	(92.70)
	Dick	58.1	100.85	110.68	120.50
		(12.2)	(66.19)	(78.73)	(92.02)
	Jim	55.3	93.58	100.58	107.58
		(10.1)	(51.72)	(61.63)	(72.05)
Landing:					
	Solly	54.9	103.17	113.89	124.61
		(12.5)	(65.27)	(79.09)	(93.41)
	Dick	53.7	101.39	112.24	123.08
		(11.8)	(61.77)	(74.26)	(87.14)
Overall Optimal		54.5	125.24	142.86	161.37
		(12.3)	(67.46)	(82.00)	(97.32)

Note: Figures in parentheses are standard deviations.

Table 3-8 Value recovery statistics - Percent recovery

Location	Log maker	DBH (cm)	Price Schedule Pessimistic	Current	Optimistic
Stump:					
	Solly	53.0	78.8	75.8	73.0
		(13.2)	(18.5)	(18.7)	(19.8)
	Dick	58.1	71.7	69.7	68.3
		(12.2)	(21.3)	(21.3)	(21.4)
	Jim	55.3	72.1	67.7	64.1
		(10.1)	(18.1)	(18.6)	(19.4)
Landing:					
	Solly	54.9	79.4	76.4	73.6
		(12.5)	(17.5)	(18.3)	(19.7)
	Dick	53.7	79.6	77.1	75.3
		(11.8)	(14.9)	(16.6)	(18.4)

Note: Figures in parentheses are standard deviations.

3.5.2 An analysis of value recovery using paired stems

Fifty two of the trees marked by Solly at the stump were also marked and manufactured into logs by him at the landing. This gave a reasonable sample size for carrying out a paired t-test to see if any differences could be detected in either dollar value recovery or percent value recovery when he manufactured logs at a stump and a landing.

For the 52 paired stems Solly achieved a mean value recovery of $115.64 at the stump and $118.14 at the landing. Although the mean value recovery is higher at the landing, when tested at the $p=0.05$ level, it was found that the difference was not statistically significant. One would have had to have tested at a p value greater than 0.4 before the difference would have been considered significant.

Solly achieved a mean percentage value recovery of 77.7% at the stump and 78.9% at the landing. Again, it was found that the difference was not significant. For percentage recovery, one would have had to have tested at a p value greater than 0.5 before the difference would have been considered significant.

A very small sample of 7 paired stems were marked by Dick both at the stump and at the landing. Although I have little faith in using such a small sample, the results are reported for completeness. There was a \$11.55 difference in mean value recovery between the stump and the landing (\$140.49 and \$152.04 respectively) but the difference was not statistically significant. In percent recovery terms there was a 15.5% difference (66.3 and 81.8% respectively), but this was also not significant. Both measures of value recovery would have had to have been tested at the p=0.3 level before they would have been found significant.

3.5.3 Results of Giant Size Regression Analysis

3.5.3.1 Dollar value recovery - Current price schedule.

Using the GSR analysis technique it was found that there was no statistical evidence to suggest separate slopes for a value recovery/diameter breast height relationship for the different log manufacturers working at the stump and the landing. The F test was carried out at the p=0.05 level. A series of tests were then done to see if there was any evidence to suggest using separate intercepts for any of the data classes. An intercept significance matrix is shown in Table 3-9. It can be seen from the matrix that in all cases actual recovery was significantly different from optimal recovery determined by the AVIS computer program. It is also evident that there is a significant difference in recovery between Dick manufacturing logs at the stump and at the landing. On the other hand, there was no evidence to suggest the need to use different intercepts for Solly manufacturing logs at the stump or the landing. Surprisingly, the GSR technique indicated that there were no differences in dollar value recovery between Solly, Dick, and Jim at the stump, and between Solly and Dick at the landing. For a given tree-size (i.e. DBH), the large range in quality characteristics, causing variability in dollar values, masks some of the people and log-manufacturing location differences. The section on percent value recovery (3.5.3.3) should highlight this point.

3.5.3.2 Dollar value recovery - Sensitivity analysis

Data from the pessimistic and optimistic price schedule were analysed in separate regressions from the current schedule. When the GSR technique was used to analyse the data from the pessimistic and optimistic price schedules it was again found that there was no evidence to suggest using separate slopes for different

Table 3-9 Intercept significance matrix* for $ value recovery

	Stump Solly	Stump Dick	Stump Jim	Landing Solly	Landing Dick
Optimum	<.01	<.01	<.01	<.01	.05
Stump:					
Solly		.2	>.5	>.5	.3
Dick			.2	.2	.05
Jim				>.5	.3
Landing:					
Solly					.2

* Note: Figures in this table are probability levels (p-value) that one would have to test at before differences were considered to be significant. Bold figures were considered to be significant by the author (p less than 0.1).

data classes. The intercept significance matrices had the same significance/non-significance relationships as shown on the matrix for the current price schedule, although the p-values changed slightly in some cases. Varying the prices paid for higher grade logs by plus or minus 20% had little effect on relative value recovery relationships between log manufacturers and log manufacturing locations.

3.5.3.3 Percentage value recovery - Current price schedule

It was found that there was no statistical evidence to suggest the need for separate slopes for the different log manufacturers processing logs at the stump and at the landing. Analysis of the percentage value recovery data using GSR techniques did indicate, however, that separate intercepts were needed for some of the data classes. Table 3-10 shows the intercept significance matrix for percentage value recovery for the current price schedule.

With some of the variation in quality removed it can be seen that more differences between log manufacturers and manufacturing locations show up as being statistically significant. Solly had significantly different (i.e. higher) recovery from Dick and Jim when all three of them were manufacturing logs at the stump. When manufacturing logs at the stump Dick and Jim were equally as good (or bad).

When Dick moved to the landing his value recovery pattern improved considerably (c. 9%). There was found to be no significant difference between his recovery and Solly's recovery on the landing.

No significant difference was found between Solly's recovery pattern at the stump and at the landing. He consistently performed relatively well in either location.

The intercept significance matrix indicates that the data classes can be separated into two regression lines with a common slope as shown in Figure 3-5. It appears that there is a trend for poorer percentage recovery with smaller stems. The regressions lines are not very useful as predictive tools, not only because they relate to specific people, but also because the coefficient of multiple determination for the combined regression was very low (0.10).

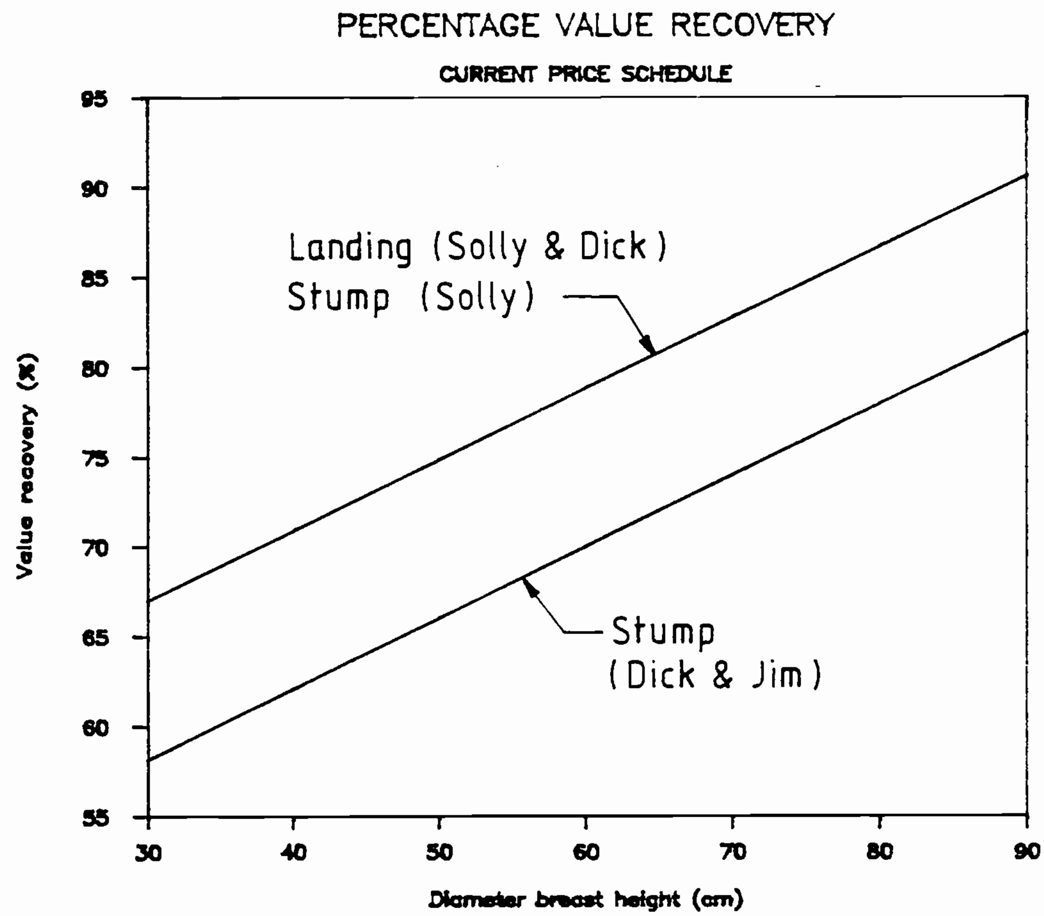


Figure 3-5 Combined regression lines for value recovery for the current price schedule.

Table 3-10 Significance matrix* for percentage value recovery

	Stump		Landing	
	Dick	Jim	Solly	Dick
Stump:				
Solly	.10	.01	>.50	>.50
Dick		>.50	.10	.05
Jim			.01	.01
Landing:				
Solly				>.50

* Note: Figures in this table are probability levels (p-value) that one would have to test at before differences were considered to be significant. Bold figures were considered to be significant by the author (p less than 0.1).

3.5.3.4 Percentage value recovery - Sensitivity analysis

There was no statistical evidence to suggest that separate slopes were required for the different data classes when the GSR analysis was carried out on the percentage value recovery obtained under the pessimistic and optimistic price schedules. The analysis did suggest the need for different intercepts in some cases however. The same significance/non-significance relationships were found for the pessimistic price schedule as for the current price schedule; i.e., it could be said that Solly was significantly better than Dick and Jim at the stump, Dick was as bad as Jim at the stump, Dick was better at the landing than at the stump but no better than Solly at the stump. The p-values at which differences would be classed as significant were generally smaller for the pessimistic price schedule than for the current price schedule. Varying the price paid for higher grade logs by minus 20% did not alter the conclusions one would make.

Some of the relationships which were significantly different under the current price schedule became non-significant under the optimistic price schedule. The p-values for a significant difference between Dick and Solly manufacturing logs at the stump, and between Dick at the stump and Solly at the landing increased from 0.1 to 0.2. I believe that this is an anomaly of the optimistic price schedule data and that the differences are still real. Figure 3-6 shows that the coefficient of variation for each of the data classes gradually increases from the pessimistic, through the current, to the optimistic price schedule. The coefficient of variation is greatest for Dick manufacturing logs at the stump. While the coefficient of variation gradually increases, the mean percentage value recovery, as was shown in Table 3-8, gradually decreases. As a result some of the differences became non-significant.

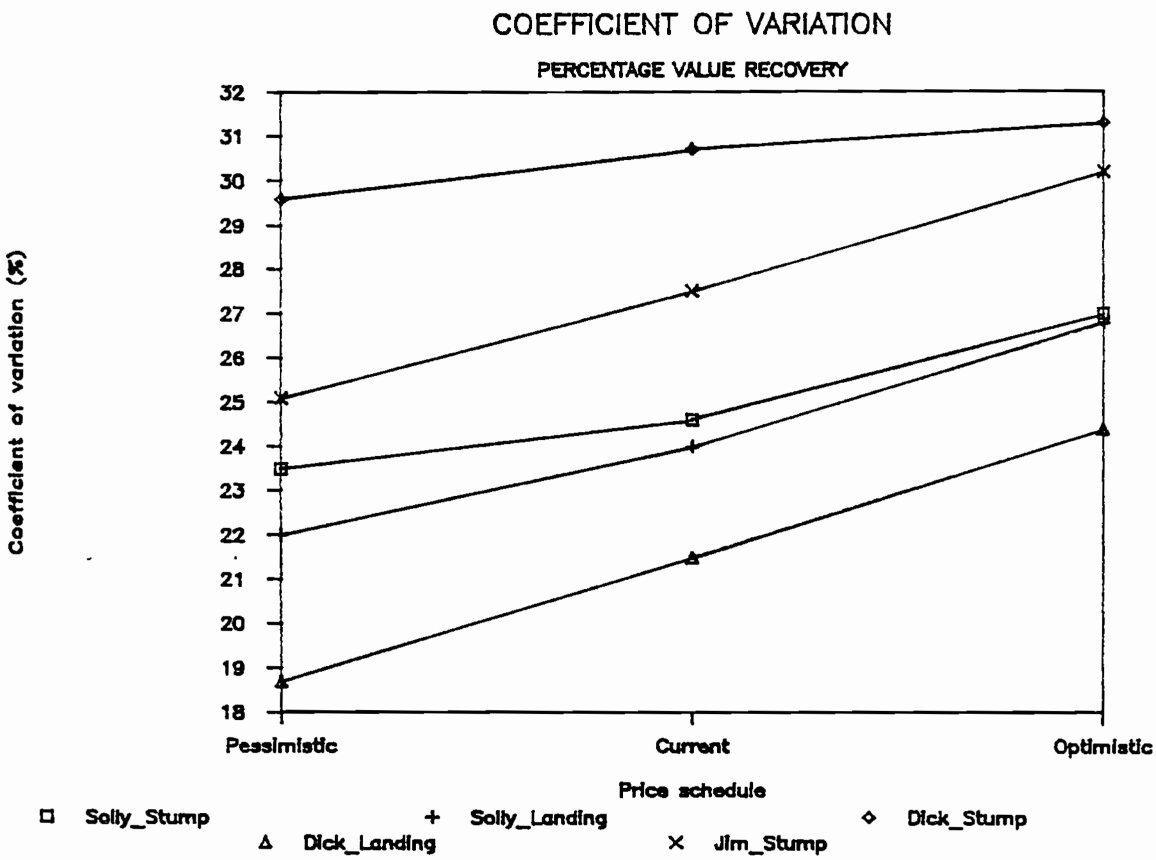


Figure 3-6 Variation in percentage value recovery.

3.5.4 Causes of value loss

Figure 3-7 shows the optimal distribution of volume by log type for the current price schedule. Deviations from this distribution, which result in sub-optimal value recovery, are shown in Figures 3-8 to 3-12 for the three log manufacturers processing stems at the stump and at the landing. To focus on causes of value loss three main points need to be looked at:

(1) Were there any log types unduly emphasised, or de-emphasised, in actual recovery patterns compared to the optimal solution ?

(2) What proportion of the logs cut did not meet specification ?

(3) What type of features were overlooked in out-of-specification logs ?

3.5.4.1 Undue emphasis on particular log types

A major cause of value loss was the downgrading of potential peeler material. Over 7% of the volume, for the optimal recovery distribution, was in the short butt and short internodal peeler log types. It should be evident from Figures 3-8 to 3-12 that the log manufacturers at both the stump and the landing had a marked reluctance to

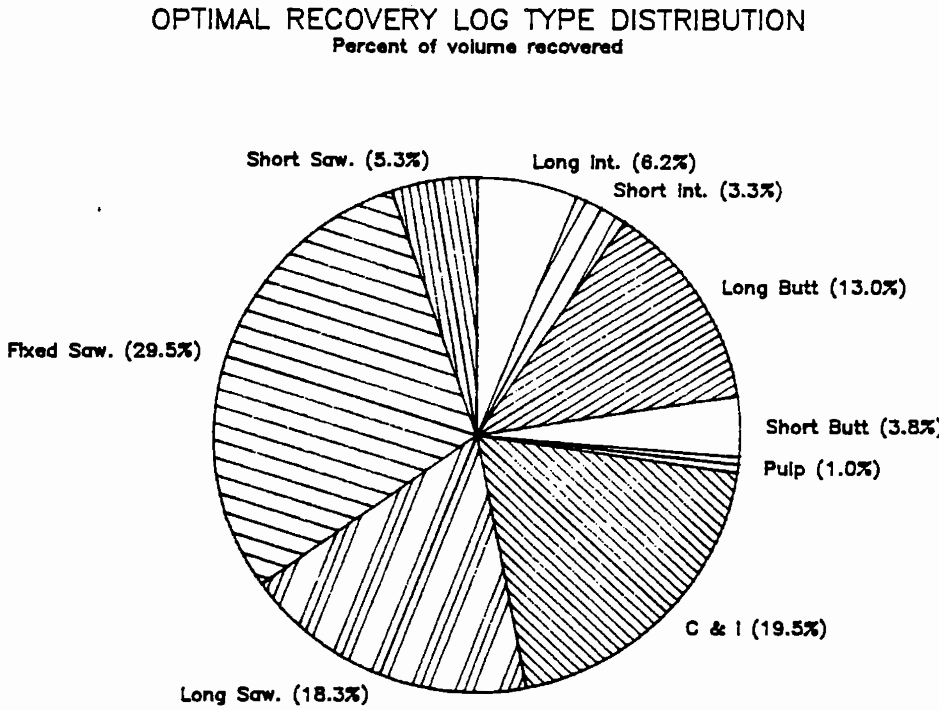


Figure 3-7 Volume distribution by log type for the optimal recovery using the current price schedule.

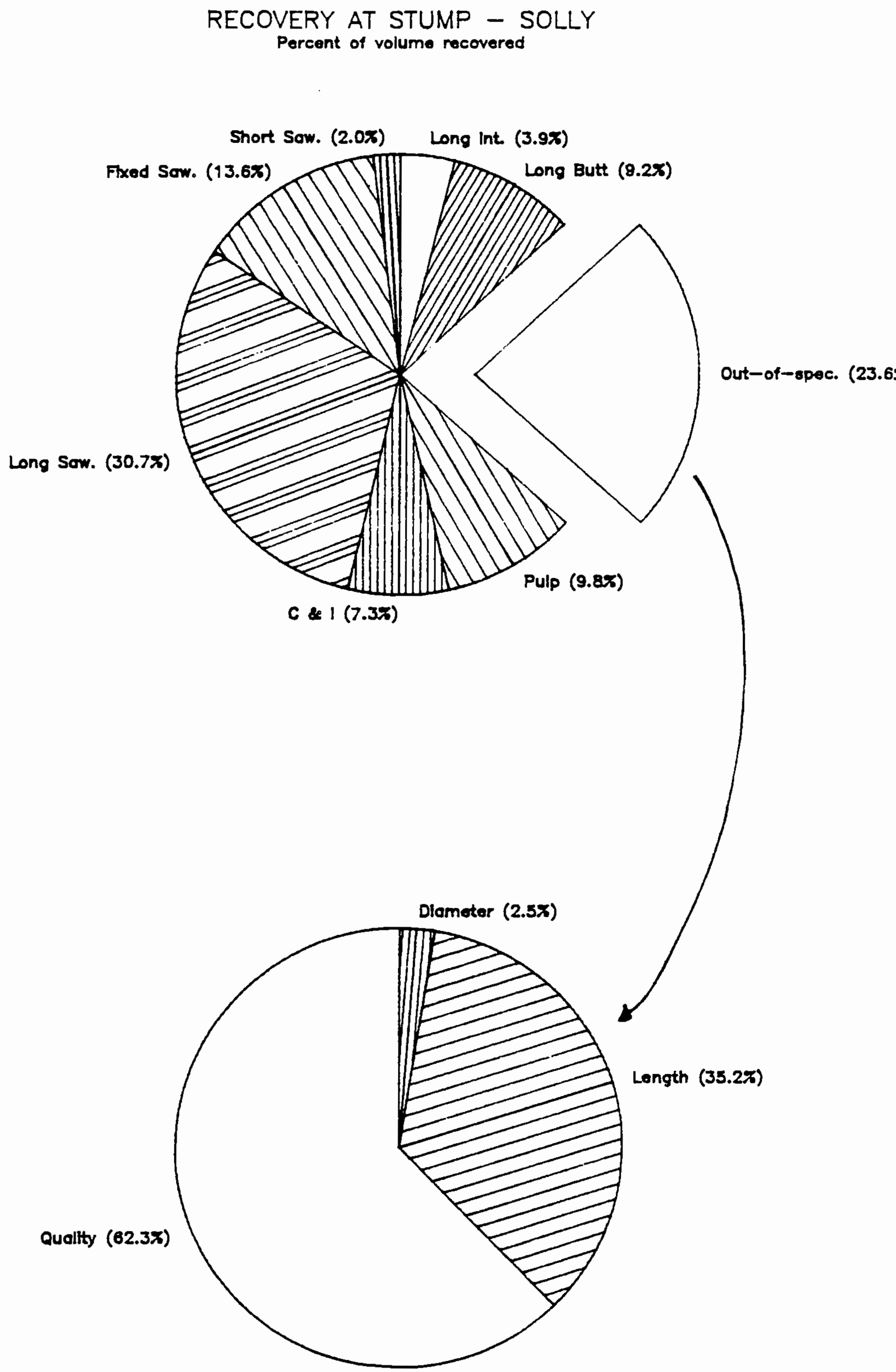


Figure 3-8 Volume distribution by log type for recovery at the stump by Solly.

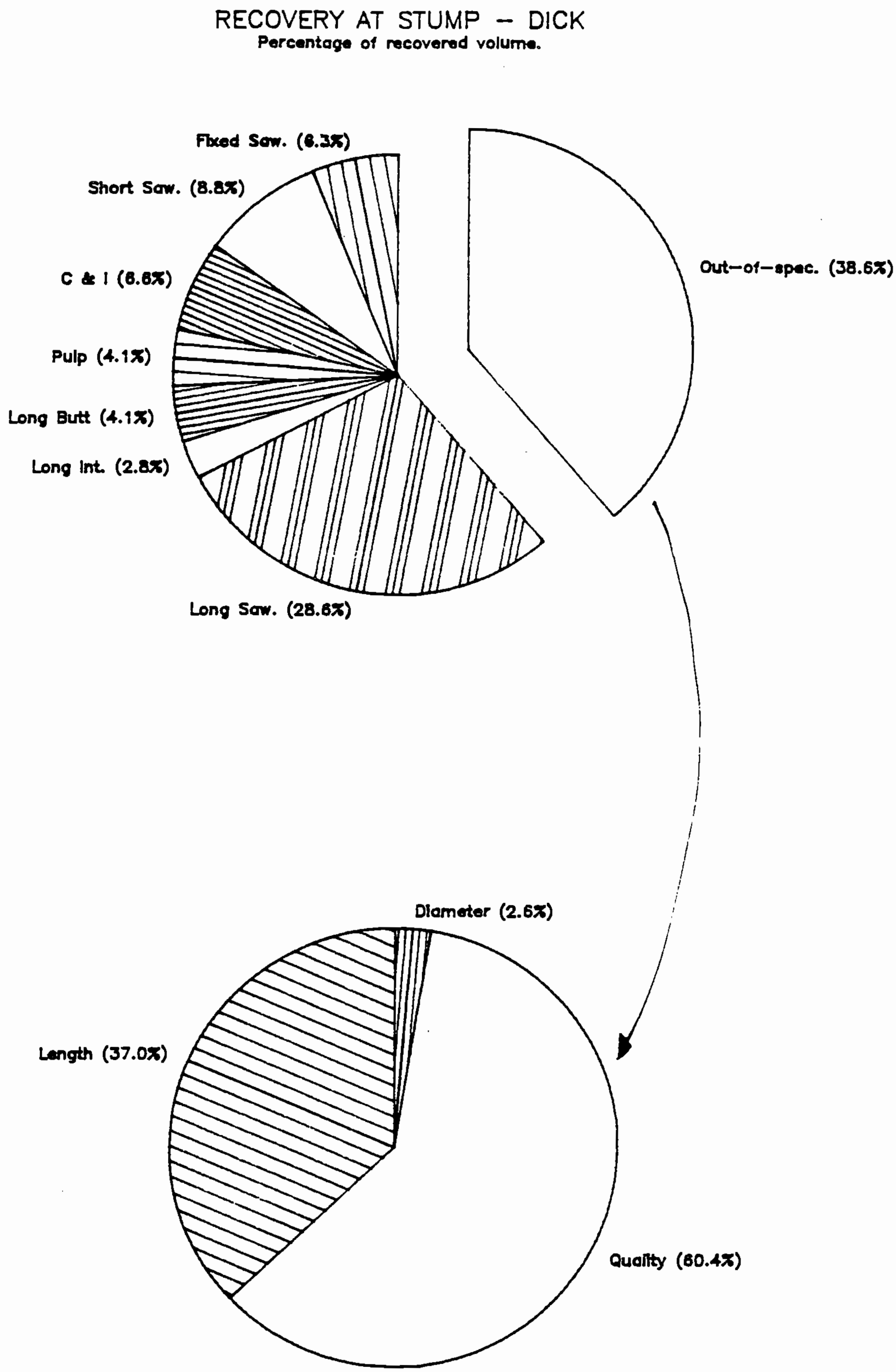


Figure 3-9 Volume distribution by log type for recovery at the stump by Dick.

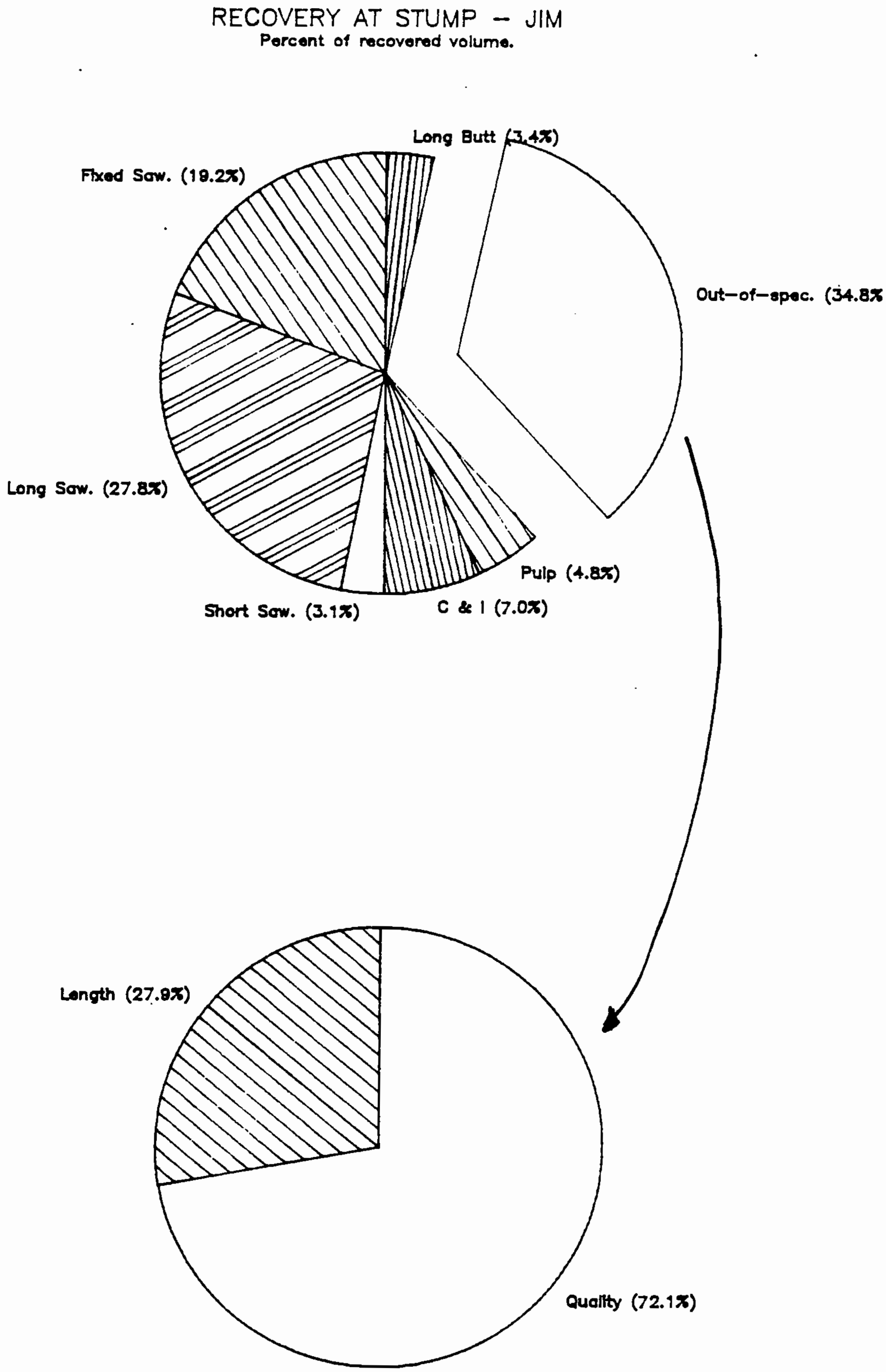


Figure 3-10 Volume distribution by log type for recovery at the stump by Jim.

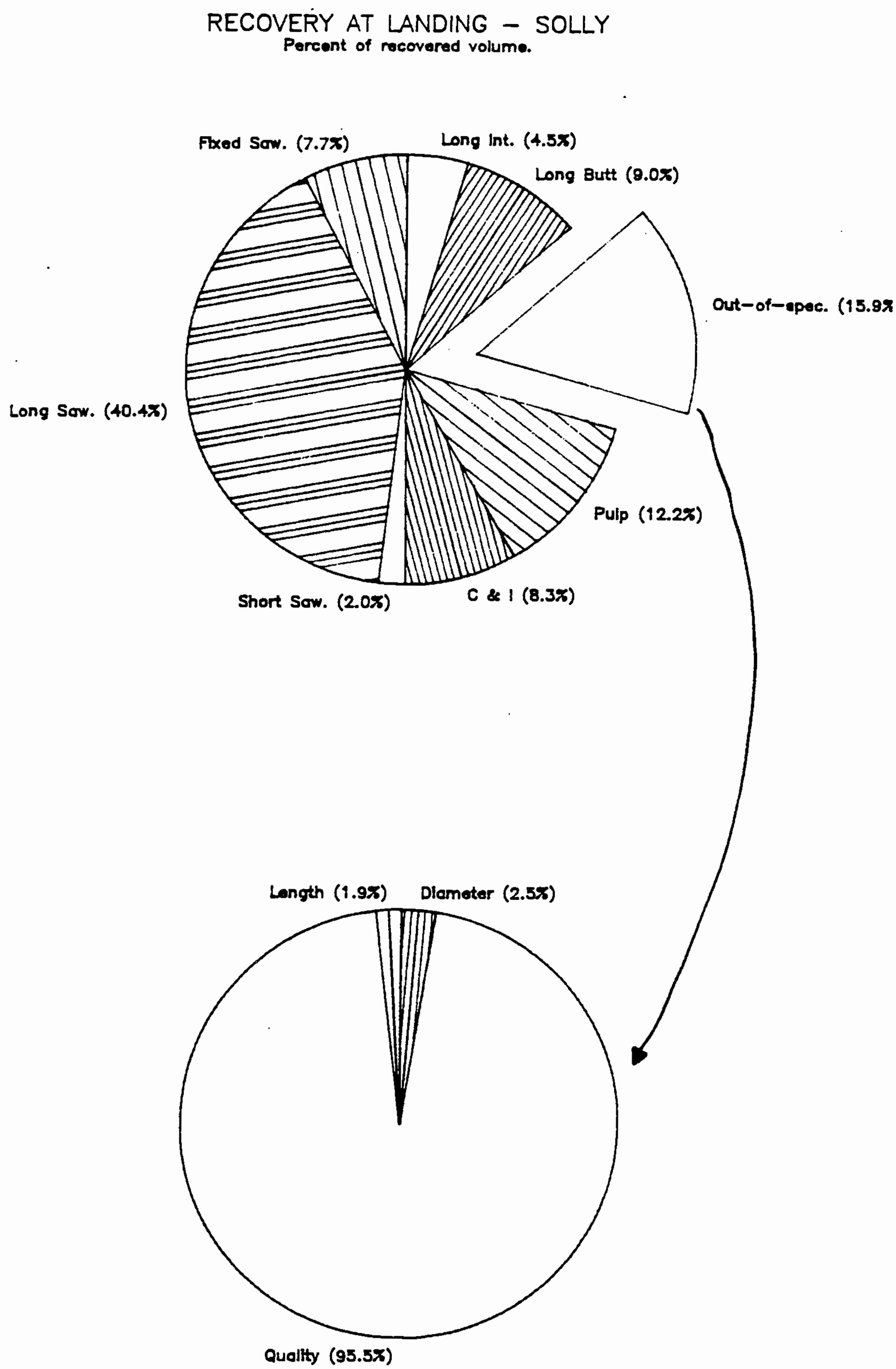


Figure 3-11 Volume distribution by log type for recovery at the landing by Solly.

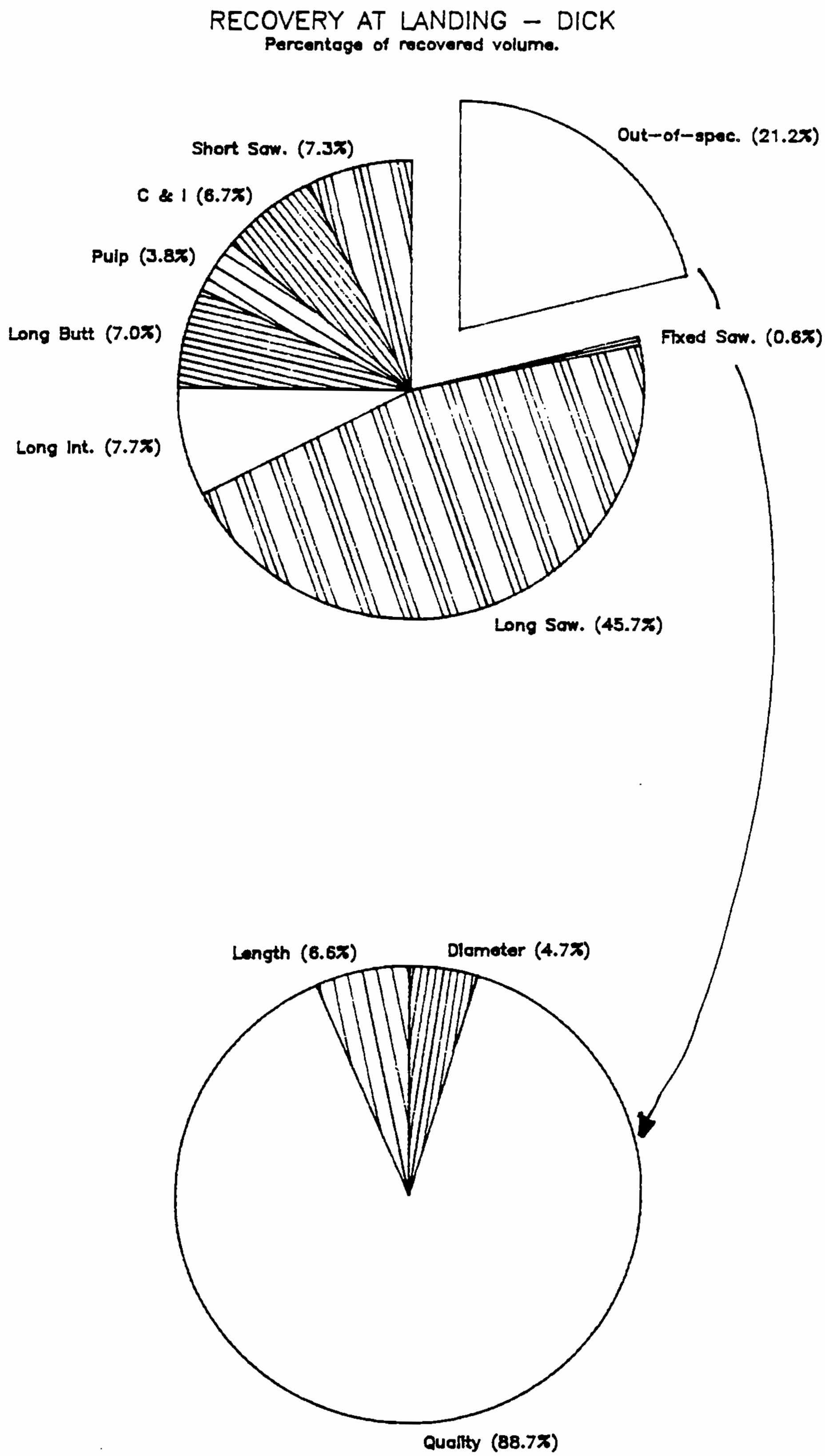


Figure 3-12 Volume distribution by log type for recovery at the landing by Dick.

cut either of these log types. For the 143 tree sample used in the study, and, indeed, for the whole time the study team worked with the logging crew, there were no short length peelers cut. Although the short length peelers were 2 to 2.5 times as valuable as sawlog material the log manufacturers were reluctant to cut these log types since they were difficult for the loader operator and the trucker to handle. Eleven percent of the total value for the optimal recovery pattern was in the short length peeler log types.

Almost 20% of the volume was in C & I peelers for the optimal solution. Less than 10% of the volume cut by the log manufacturers was in this log type. It would appear that the log manufacturers were cutting to a higher quality than specified for this log type.

There was a $2 premium for fixed length (12.3 m) sawlogs over random length sawlogs ($34 versus $32) which resulted in almost 30% of the volume in the optimal solution being cut into fixed length sawlogs. The highest proportion of fixed length sawlogs cut by any of the log manufacturers was 19% - most of the sawlogs cut were random lengths. There is evidence, albeit weak, that there was more emphasis on cutting random lengths at the landing than at the stump. As cited in 3.2.5

Twaddle (1984) has observed other log manufacturers preferring to cut random length sawlogs so that extraction productivity was not limited by delaying the tractor on the landing. The same preferrence may have occured during this study.

There was a marked emphasis on downgrading potential sawlog material into pulpwood at both the stump and landing. About 1% of the volume would have been cut into low value pulpwood under the optimal recovery pattern. Anywhere from four to twelve times this proportion was cut by the log manufacturers. With sawlogs worth over twice that of pulpwood ($32 versus $14) this increase in pulpwood quantity significantly reduced the value of the actual cutting solutions.

3.5.4.2 Proportion of logs not meeting specifications

One thing that is strongly evident from Figures 3-8 to 3-12 is that, for all log manufacturers, a significant proportion of the logs cut did not meet specification. The proportion of out-of-specification logs ranged from 15.9% for Solly at the landing to 38.6% for Dick at the stump. Logs which do not meet specification are not worthless since they can generally be remanufactured into lower grade logs. They are, however, a considerable cause of lost value. From figures such as these, and such as have been reported by Twaddle (1986), it is understandable why many value recovery quality control schemes first aim at reducing the number of logs that do not meet specification.

There were large differences in the proportion of logs not meeting specification for the different log manufacturers. At the stump, Dick and Jim had about one and a half times the proportion of out-of-specification logs as Solly (38.6% and 34.8% versus 23.6%). At the landing, Dick was, again, considerably worse than Solly (21.2% versus 15.9%).

Both Solly and Dick dramatically reduced the proportion of out-of-specification logs they cut at the landing compared to at the stump. The proportion fell from 23.6% to 15.9% for Solly, and from 38.6% to 21.2% for Dick. Although far from perfect, this was an improvement. A better view of the stem may have be obtained at the landing and fewer dimension and quality features overlooked.

3.5.4.3 Features missed on out-of-specification logs

The log manufacturers may have missed several features which resulted in logs being classed as out-of-specification. The feature which resulted in the greatest loss in value was used to categorise out-of-specification logs, as reported here.

By far the most commonly missed features were quality related for the three log manufacturers at the stump and two at the landing. The type of quality features missed include out-of roundness, occurrence and size of branches, sweep, and felling damage. About two thirds of the out-of-specification logs marked by Solly, Dick, and Jim at the stump resulted from missed quality features. Over 90% of the features missed at the landing were quality features.

Much of the literature related to differences between log manufacturing at the stump and at the landing cites a reduction in dimension-related out-of-specification logs at the landing. If Figures 3-8, 3-9, and 3-10 are compared with 3-11 and 3-12 it can be seen that the proportion of dimension-related missed features drops considerably at the landing. In fact, much of the overall improvement in the proportion of logs which met specification at the landing (as described above) was due to the greater accuracy in length measurements. The proportion of total volume that did not meet specification due to inaccurate length measurements fell from 8.3% at the stump to 0.3% at the landing for Solly. The reduction was even more dramatic for Dick; from 14.3% down to 1.4%.

There was a much higher incidence of logs which did not meet length specifications than did not meet diameter specifications. The absolute proportions remained the same for diameter-related missed features at the landing as at the stump; i.e., less than 1%.

Some of the differences in the amount of value recovered by the different log manufacturers was undoubtedly due to their ability to meet log specifications. Figures 3-8 to 3-12 highlight the differences that can occur in this ability between different people at the stump and at the landing. Given that the same tools were available and the same field conditions were experienced by each of the log manufacturers the differences must have been due to human factors such as motivation, perceptual abilities, and motor abilities.

3.6 CONCLUSIONS

Before drawing conclusions from this study it is necessary to stress that it was carried out in a single stand, on three log manufacturers, using only one set of log specifications. The conclusions are therefore limited by the breadth of the study and must be treated accordingly. The work by Landerud and others (1973) however, has pointed out the variability in value recovery achieved by different log manufacturers and confirms some of the conclusions of this study. Their work also highlighted the need to study the same log manufacturers, working in the same stands, if the effects of different log manufacturing alternatives were to be identified. This study used such an approach. So although it may not have had the breadth of Landerud's study, I believe it had more depth.

The main results and conclusions of this study can be summarised as follows:

(1) It was found that there was a significant difference in dollar value recovery between the theoretical optimal log manufacturing patterns, as determined by a dynamic programming optimisation algorithm, and the value recovered by log manufacturing personnel in the field. For the log prices used in New Zealand at the time of

the study this difference amounted to about $30 per tree, or about $10 per cubic metre.

(2) Expressing value recovered for a given stem as a percentage of the optimal value was found to be a better measure than dollar values alone for testing if there were people differences or log manufacturing location differences in the study data.

(3) In terms of objective 2 analysis indicated that people differences were, in fact, present. Firstly, there were significant differences in value recovery at the stump between the three log manufacturers. Secondly, the two log manufacturers studied at the stump responded differently to working on the landing; although there were increases in mean value recovery for both log manufacturers an increase was only found to be significant for one of them.

(4) In terms of objective 1 the results show that there were significant differences in value recovery when logs were manufactured at the stump versus on a landing. Manufacturing logs at the landing appears to be, at least as good as, and possibly better than manufacturing logs at the stump if value recovery is used as a criterion for comparison. If log manufacturers with similar (or greater) skills to Solly are always available there may be no significance difference in recovery.

(5) For objective 3 the sensitivity of these conclusions to changes in the price paid for higher quality log grades (with concomitant tighter log specifications) was tested by varying peeler prices by plus and minus 20%. Although minor differences occurred the relativity and conclusions remained stable.

(6) As has been found in other value recovery studies carried out in New Zealand, downgrading of peeler material to sawlog grades, and sawlog material to pulp grades was a major cause of value loss. The marked reluctance of all the log manufacturers to cut short length peeler grades was particularly noted.

(7) A large proportion of the logs manufactured did not meet specifications. There appeared to be a smaller proportion of the log volume on the landing than at the stump which was out-of-specification (about 20% versus 30%). Some of the log manufacturers were worse than the others. For example, percent of volume out-of-specification ranged from 23.6% to 38.6% at the stump.

(8) Improvements in log length accuracy are often cited as one of the benefits of processing on a landing. This study noted an improvement in the accuracy of log lengths manufactured on a landing, in the order of a

magnitude of difference, over that found for manufacturing at the stump.

(9) Although improvements in length accuracy were found, as indicated in the literature, missed quality features were found to be the greatest cause of lost value in out-of-specification logs in this study. Two-thirds or more of out-of-specification volume resulted from missed quality features, such as sweep, felling damage, and oversize branches.

3.7 RECOMMENDATIONS FOR FUTURE RESEARCH

As discussed in 3.6 above the conclusions that can be drawn from this study are limited by its breadth. I would recommend the following course of action to expand the conclusions:

(1) The study should be repeated in more stands on steep country throughout New Zealand. The number of stands required will depend on the variability found. The stands should be representative of those to be harvested in the near future.

(2) The number of stems studied per stand should be reduced, possibly to as low as 25, to reduce the time required and cost of the study. The actual number of stems required will depend on the variability found.

(3) Percentage value recovery should again be used as the main independent variable as it reduces the variability associated with differing levels of quality in stems of the same size.

(4) It is absolutely necessary that stems be marked into log lengths by the same people at the landing as did so at the stump. It is not necessary that the same person be used for all future studies. On the contrary it is important that more log manufacturers be studied to determine the magnitude of the variability among manufacturers.

This study indicated that people differences may be more important in value recovery than log manufacturing location. Research needs to be carried out to see if these differences are due to basic inherent abilities which people possess or are skills which could be identified and developed by training, and encouraged by effective incentives schemes.

CHAPTER 4. POTENTIAL VALUE RECOVERY AT A CENTRAL PROCESSING YARD.

ABSTRACT

Since radiata pine stems would be too long for transport to central processing yards within New Zealand on conventional trucks, some sawcuts would have to be made in the forest. These initial cuts would pre-empt future bucking decisions. Three cutting patterns (fixed 11.1 m lengths, fixed 12.6 m lengths, and fixed cutting zones) were applied to 143 radiata pine trees from a 40 year old plantation forest to see what effect these pre-emptive cuts would have on potential value recovery at a central processing yard. Potential value recovery for all three patterns was in the middle ninety percent range. Significant differences in percent value recovery were found between the three cutting patterns; with the fixed 11.1 m pattern being the worst and the fixed cutting zone pattern being the best. Most of the reduction in value for the fixed length cutting patterns can be attributed to an overall reduction in the amount of peeler volume cut and a redistribution of the volume from long length peeler logs to short length peeler logs.

4.1 INTRODUCTION

The large increase in the amount of timber harvested in New Zealand from steep and unstable terrain over the next two to three decades has been discussed in previous chapters. This upcoming change has forced us to re-examine where, in the chain of activities from stump to mill, log manufacture and segregation should take place. There are several locations where log manufacture and segregation could take place - the felling-site, the landing, a centralised processing yard (CPY), or at a merchandiser at the processing plant. The decision on which is the best option for particular circumstances within New Zealand will require a good understanding of how these options affect value recovery and harvesting costs. Value recovery at the felling-site and at the landing were examined in the previous chapter. This chapter examines some issues related to value recovery at a centralised processing yard.

There are many synonymous terms in the literature for centralised processing yards - central conversion sites, centralised conversion landings, timber terminals, and lower landings (Wipperman, 1984). Other facilities, which have similar characteristics to CPY's, are central sortyards (where the predominant activity is sorting for value) and merchandising yards (where capital intensive, sometimes computer-aided, log manufacturing is carried out). Basically, within a certain forest district timber is harvested at various logging sites, accumulated in one place, converted at this "central" point and afterwards distributed to linked plants or marketed over long distances. The raw material may be brought to the CPY in various forms - whole tree, full-tree, tree-length, long length, or short log length (Filer, 1978) - and there are many different designs for CPY's. Sincalir and Wellburn (1984) discuss in detail the factors effecting the design, construction and operation of central sortyards.

The relationship of the centralised log processing yard to other logging systems can be explained by looking at two important but conflicting principles in logging. These are: (1) avoiding unnecessary transport of all unusable material, and (2) removing all work possible from the difficulties of the forest environment and concentrating it at a central conversion site (Sundberg, 1966). Carrying out all the processing of the tree into logs at the stump is in accord with the first principle, while whole tree logging with processing being done at a central facility is the result of placing all the emphasis on the second principle. In between these two extremes are a whole range of compromises giving us many different harvesting systems.

Centralised processing of logs from plantation forests appears to have great potential where in-stand harvesting systems are limited by difficult terrain and environmental factors, or where timber is sold according to different length, diameter and quality specifications, and where residues can be used for fiber or energy (Kerruish, 1984). Centralised log processing can give the advantages that come with having a fully integrated manufacturing facility without requiring that different log users occupy the same location (Anon, 1973). The concept is particularly appropriate when the resource consists of a large number of small trees of varying quality (Murphy, 1978).

The benefits of establishing CPY's can be split into two main categories; productivity/cost related and value-recovery related. This chapter concentrates on the latter category. Chapter 5 will address the productivity/cost related issues.

4.1.1 Centralisation of decision-making

There are many reasons why CPY's are established. Hampton (1981) believes that the immense impact of an [incorrect] bucking cut on overall profitability and the less-than-ideal conditions in the forest has given impetus to the merchandising concept at a centralised facility. Wahl (1979) similarly states that "bad and inexpert cross-cutting can cause more losses in financial return than any other operation in the processing chain from falling to the finished product emerging from the sawmill, veneer mill, or plywood mill. The ideal situation is one where bucking can be carried out in the millyard where adequate equipment and trained staff are available".

The trend towards mechanisation of forest activities and removing work from the forest environment has also brought about an increase in the number of CPY's being built in many countries around the world (Filer, 1978). Duffner (1981), a West German CPY owner, believes that there will be a trend towards full-tree logging and away from conversion at the stump. Computer-supported decision-management systems will result in a movement away from decision-making in the forest and toward a centralisation of the decision-making process. The decision to utilise a centralised wood processing facility offers increased opportunity, [particularly] for large vertically integrated firms. The use of mathematical optimisation tools in this environment is greatly facilitated and offers great promise for firms engaged in CPY activities because many stem conversion decisions can be made at a central site (Bare et al., 1979).

The gains in improved value recovery obtained from computer-aided log manufacturing may be dependent on the skills of the conventional log manufacturers. In West Germany Durrstein (1985) has found that computerised log manufacturing systems gave 6% more value recovery than did conventional systems. Ailport (1981) found that a 3% increase was found for computerised log manufacturing of small trees (< 28cm at butt) in the north-western United States of America. Wachtmeister (1984) found for a Swedish Forest Service CPY facility, that in a test of the economical output of computer- aided optimisation equipment value recovery was increased by 2 to 4% compared with their extremely skilled operators. Morenius (1981) states however that computer-aided log making with scanning equipment is not a panacea and should not be used for large timber. He reports a study carried out by the College of Forestry in Sweden which found a US$5 per cubic metre gain in value from accurate human processing of stems compared with mechanical processor log-making.

Many CPY's do not rely on computer-aided optimisation techniques for log manufacture decision-making. Improved decision-making is still claimed for these facilities (Sinclair, 1985). Centralising the point of primary log allocation allows for greater control of decisions and greater ease of auditing of key operator performance. Decisions become centred on fewer log manufacturers who are specialists (Harmon, 1977, Manly, 1984). Rotherham (1978) reported that when Consolidated-Bathurst Ltd. in Canada began establishing CPY's in their forests one specialist log manufacturer was able to replace 14 log manufacturers on separate landings and still do a better job of recovering the maximum value out of the stems.

Changing to a centralised processing system has several advantages for the labour that is employed. Firstly removing all the log processing from the forest reduces the amount of labour required in the forest where work conditions are often difficult and transfers them to a central yard where work conditions will be superior in terms of safety and comfort. With more complete mechanisation the jobs are not as physically demanding. Because fewer and more skilled personnel are employed, under better working conditions, labour turnover should be reduced. Furthermore, as the labour force is concentrated in the yard rather than spread over the forests, supervision and control are easier. All these factors should lead to better decision-making (Filer, 1978).

Centralising the log processing activities also leads to improved value recovery in areas other than decision-making. Wachtmeister (1984) has found gains in value recovery due to higher technical precision in the form of improved log length and diameter accuracy. CPY managers are also able to react to changing market conditions and short term profit opportunities easier and quicker than logging crews working in the forest (Lewis, 1974, Filer, 1978, Wachtmeister, 1984). They have the ability to make rapid changes in cutting instructions (Bankston, 1974). This ensures a better return from each tree. Improved value recovery is also obtained by being able to concentrate volumes so that specific orders for uncommon products may be met. For example, Manly (1984) has reported that there are several hundred small CPY's operating and surviving in West Germany on their ability to meet specific orders. Twenty plus log sorts are not uncommon for many of these yards. Specific orders are being met which would have been impractical if log manufacturing were carried out in the forest.

Residues arising from topping, delimbing, debarking and bucking are readily accumulated at a CPY and available for utilisation. Value is recovered which may have been uneconomical in the forest.

4.1.2 Value gains

Although improved value recovery is often claimed as a benefit of establishing central processing yards studies quantifying the value gains over conventional systems are sparse.

Grammel (1981) found a 5 to 7% increase in volume recovery and an increase in value recovery for full tree operations. The actual increase in value was not specified, however. Sinclair (1980), describing sortyard operations in British Columbia, reported an increase in revenue of about C$2000 per day from a full time bucker upgrading only 20 to 30 logs per day. A study carried out by Landerud and others (1973) in Norway found a small improvement (c. 2 Norwegian Crowns per cubic metre) in value recovery at a central processing yard compared with processing on a landing under winter conditions. One of their conclusions was, however, that differences between log buckers may have been more larger than differences between log manufacturing location. The small improvement may not reflect the true level of value gain. Manly (1984) reported that a CPY (Holzhof Furstenberg - Donaueschingen) in West Germany reduced the proportion of low value pulpwood harvested from local forests from about 30% of forest outturn to about 5%. Sibal and others (1984) compared the profitability of several types of merchandiser systems in the north-eastern US with conventional harvesting systems. Profitability and value recovery were higher at the merchandising yard but this was due to an assumed US$2/cord premium for clean chips over chips containing dirt and bark.

Kerruish (1984) describes value recovery gains from establishing CPY's which are quite large. Firstly, the Swedish Forest Service recently opened a central processing station in Eksjo that supplies log products to accurate dimensions and graded into quality classes. The

Swedes say product value has gone up 40% over their conventional harvesting operations. This improvement in value recovery was achieved without the aid of electronic optimising equipment. They expect further increases in recovery when this equipment is installed. Secondly, of more relevance to New Zealand, he reported a 1979 study carried out by the CSIRO Harvesting Research Group in early radiata pine thinnings in the Australian Capital Territory. Compared with conventional harvesting systems (chainsaw felling, delimbing, bucking, forwarder extraction) a small increase in volume recovery and a 24% increase in value recovery across all products was found for a CPY.

Not all of the literature lauds the CPY concept. Schultz (1984), general manager of APM Forests Pty. Ltd. in Australia, states that "Central processing would appear to be an expensive luxury which could only be justified by substantial product upgrading and appreciable value differentials." Woodyards must compensate higher costs with a higher yield and an increase in wood quality. The central question is if these increases are always possible (Grammel, 1984). Manly (1984) reports that log upgrading at Holzhof Zeil in West Germany in 1982 cost 40 DM/cu.m. but only gave an increase in value of 29 DM/cu.m.. 1982 was considered to be a bad year, however.

Wachtmeister (1984) reports that "it is obvious that longwood methods and central processing have [currently] lost all practical importance in Sweden. It has been easier to develop equipment to increase productivity rather than product value." It was thought in Sweden that mechanisation would lead to improved bucking accuracy and higher value recovery. The quality of log yields is considered to have decreased over that of experienced log buckers, however (Nasberg, 1985).

Achieving maximum value recovery, even at a CPY, is a very complex task. Potential value can be lost through poor practices in a CPY just as it can be in the forest. Based on actual experiences with many operations throughout the forest industry of the United States, Beck (1980) estimates a US$2 per cubic metre opportunity for improved value recovery in log allocation, sorting, and merchandising. Craig (1982) believes the potential gains in value through reduction of value losses at CPY's could be greater than Beck's estimation. Craig estimates gains in the order of 0 to 30%.

A reduction in costs and an improvement in value recovery at CPY's is thought to occur if some broad classification and pre-sorting of logs is carried out in the forest before transport to the CPY. For example, Holzhof Zeil in West Germany requires that logs are presorted into four diameter classes before entering the yard (Manly, 1984) and ITT Rayonier in Washington (USA) requires that logs be presorted into three broad size/species classes (Pease, 1977).

Some value loss occurs due to log damage and breakage during handling in central processing yards. Hand (1980) believes that a conservative estimate would be a half a percent loss per handling with the total loss amounting to 1.5 to 3% from the time the logs enter the yard until they leave.

Some CPY's use conveyor systems to move logs past a log bucker who decides, with or without the aid of a computer, the product types that should be cut and sorted. With these type of systems log buckers have to make 6 decisions per minute on 2000 to 3000 stems per day (Harmon, 1977, Thornquist & Wallin, 1977). Bertramm (1983) has found that production pressure to keep the conveyor moving can cause mistakes because there is little time to properly evaluate each log. He found that, at a 1,360,000 cubic metre annual capacity sortyard, handling pieces of approximately 1.5 cubic metres in size, the amount of wood missorted into wrong sorts was approximately 3.5% of the total volume.

A summary of the above literature might be that one could expect substantial gains in value recovery by establishing a CPY but one should be aware that high costs may outweigh the value gains and that adopting the CPY concept will not completely eliminate sub-optimal value recovery.

4.1.3 Application of CPY concept to New Zealand

New Zealand has had no experience with central processing yards in Pinus radiata plantation forests to date. In the mid-1970's, however, a large experimental project was underway to examine the feasibility of intensive management of some of the beech (Nothofagus sp.) forests on the South Island. Two small woodyards were established to look at the CPY concept. The logs were processed and segregated into peelers, sawlogs and pulpwood. Higher sawlog recovery was obtained but, because of the very small daily volumes passing through the yards (c. 70 cubic metres per day), unit costs were unacceptably high (Bryan et al., 1976a & 1976b).

Twaddle (1985) discusses the advantages and disadvantages of introducing large-scale mechanised log merchandising in New Zealand. He claims that the high cost of fixed plants and plant maintenance and the inability of current scanning technology to cope with surface features such as pruned lengths and knot sizes prohibits its introduction at this stage. He believes alternative options could be centralised processing yards with manual bucking where there could be better use of capital and current skills and technology. Rotherham (1978) describes a harvesting system where logs are tree-length hauled by skidder from fourteen different logging crews over a 3 km distance to a central processing yard within the forest. This system may have applicability to New Zealand. It is likely however that, in many cases, the wood would have to be carted for longer distances over public roads.

Even after felling breakages radiata pine stems are 25 to 45 m long. The average logging truck in New Zealand is a 3-axle, 203 kW truck with a 2-axle trailer set up for carting long length logs (>8 m) (Gordon, 1979). Filer (1978) points out that NZ Ministry of Transport regulations restrict total truck length to 19 m. This means that a maximum possible log length of 14 m can be carried on a conventional logging truck. Goldsack (pers. comm.), a roading engineer with the NZ Logging Industry Research Association, has found that the longest current legal long log length carted by industry is 13.7 m. Since the average stem length is substantially longer than the maximum truck length the stem would have to be cut into several pieces.

When a log is bucked unnecessarily future values are at risk (Fisken, 1981). Manly (1984) believes that initial cuts, required at the stump or roadside to reduce the stem to a legal length for transporting, reduce the advantages of the CPY concept. Later bucking decisions are pre-empted by the initial cuts and thus result in some value loss (Figure 4-1). He considered this to be a particular problem in establishing a CPY in New Zealand. The effect that "pre-emptive" cuts have on potential value recovery at a central processing yard is the research topic addressed in the remainder of this chapter.

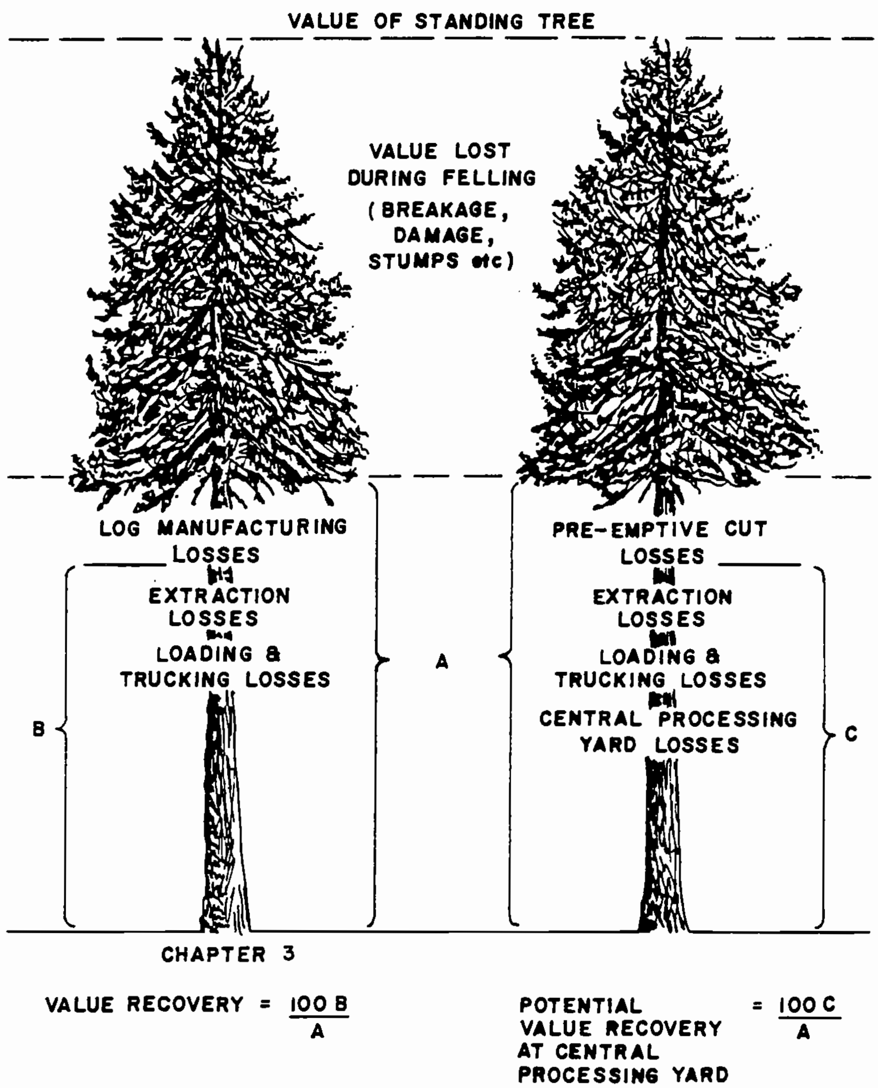


Figure 4-1 A comparison of value recovery measures in chapters 3 and 4.

Pre-emptive cuts at the stump could follow several patterns:

- cuts could be made at rigidly fixed intervals up the stem,
- cuts could be made within designated zones at fixed intervals up the stem,
- flexible cutting rules could be developed for given stem characteristics. New rules would have to be established as stem conditions changed.

Twaddle (pers. comm.), in preliminary studies, has found a 1 to 5% value loss associated with the latter pattern of pre-emptive cuts.

Dejmal (1974) compared grading, marking, and cutting logs individually against cutting to fixed lengths and concluded that any loss in value would be offset by higher extraction machine productivity. Haggblom and Pennanen (1983) found no difference in value recovery between random length and fixed length cutting in Finland. If fixed lengths are cut one could expect the longer they are the better the value recovery. Clarke

(1986) found that harvesting long lengths up to 20 m instead of the conventional 15-16.5 m resulted in reduced logging costs, reduced site disturbance, improved safety, and increased log value. For his company there was an expected gain of C$635,000 per year.

4.2 STUDY OBJECTIVES

Log manufacturing and sorting of forest products at a central processing yard is an alternative to log manufacturing (on a large landing) that New Zealand must consider for steep country harvesting. It is extremely unlikely that radiata pine will be trucked in tree length form to central processing yards because of its weight and long lengths. If the tree lengths are cut into truck lengths at the stump some value will be forgone as a result of the pre-emptive cuts made. The objectives of this study are to:

(a) quantify the level of value forgone by cutting fixed truck lengths of 40 year old radiata pine at the stump ,

(b) determine if there is any difference in value recovery for different fixed length cutting patterns.

4.2.1 Hypotheses

It is hypothesised that there is no significant difference in potential value recovery between the following "fixed" length cutting patterns:

(a) cutting stems into fixed lengths of 11.1 m

(b) cutting stems into fixed lengths of 12.6 m

(c) cutting stems into truck lengths by imposing a cutting zone at a fixed interval up the stem. A cutting zone is a region on the stem in which a cut must be made.

4.3 STUDY DESIGN AND METHODS

4.3.1 Dependent variables and sources of variation

The dependent variables used in this study were similar to those used in the comparison of value recovery at the stump and the landing; that is,

(a) the monetary value of the trees measured in NZ$/stem

and (b) the maximum theoretical value that could be recovered from stems cut into fixed lengths expressed as a percentage of the optimal value solution.

Many of the sources of variation of the dependent variables for this study have previously been discussed in Chapter 3. They are listed in abbreviated form below. Other sources of variation are given more discussion.

(1) tree size

(2) stand variation

(3) site variation

(4) log manufacturing personnel - It could be expected that there would be some value loss associated with cutting logs into fixed lengths at the stump, due to length measurement inaccuracies. It could also be expected that this value loss would vary between

different log manufacturing personnel (as discussed in Chapter 3). This study does not address the issue of variations in value recovery achieved by different people. Only differences in theoretical optimal values are identified.

(5) fixed length cutting pattern - this is one of the major independent variables in this study.

(6) logs types produced

(7) log prices

Log types and prices selected for use in this study were representative of current practices in New Zealand. The log type list included both fixed and random length logs of both short and long lengths. Premiums were paid for some of the fixed length and longer length products.

4.3.2 Study methods

4.3.2.1 Stand details and harvesting system

The stems selected for this study were taken from Compartment 18 of Whakarewarewa State Forest Park. The same logging crew and stand conditions described in Chapter 3 were used for looking at the effect on value recovery of cutting stems into fixed lengths at the stump. Refer to sections 3.3.3.1 and 3.3.3.2 for the detailed descriptions.

4.3.2.2 Field procedure

The field procedure, described in detail in section 3.3.3.4., covers all that is relevant to this study and some points that are not. In summary, however, two hundred and forty trees were selected for felling in the study area, although not all 240 were used in the data analyses. After each tree was felled an AVIS field cruise was carried out.

4.3.2.3 Log specifications, qualities, and prices

The log specifications and qualities used in this study were the same as described in section 3.3.3.5. and presented in Tables 3-3 and 3-4.

Only one price schedule was used for this study; the "current" schedule in Chapter 3. It is again presented in Table 4-1 below.

Table 4-1 Log price schedule

Log type	Lengths (m)	Prices (NZ$/cu.m. under bark)
Long butt peeler	5.3	82.50
Short butt peeler	2.7	78.50
Long internodal peeler	5.3	62.50
Short internodal peeler	2.0	58.50
C & I peeler	5.3	50.00
Fixed sawlog	12.3	34.00
Long sawlog	6.0-13.3	32.00
Short sawlog	3.6-5.9	32.00
Pulp	3.2-13.3	14.00

4.3.2.4 Selection of fixed length cutting patterns

Three fixed length cutting patterns were selected for analysis in this study:

(a) 11.1 m fixed lengths. A sawcut would be made every 11.1 m up the length of the stem, i.e. 11.1, 22.2, 33.3, and 44.4 m. If the piece above the last 11.1 m length met the minimum log specifications described in Table 3-3 it was assumed that it would be classed as merchantable and would be extracted and trucked to the central processing yard. The maximum overall length for on-highway trucks in New Zealand is 19.0 m. The maximum log length that can be legally trucked is dependent on the truck configuration and is currently under review by New Zealand road transport authorities. The maximum log length carried by typical log trucks is about 14 m. Many managers set maximum log length specifications which are less than 14m to reduce the likelihood of overlength logs exceeding legal trucking limits. I selected 11.1 m for a fixed length cutting pattern since it is about 80% of the 14 m maximum and is about a metre less than the height to which the stems had been ultra-high pruned.

(b) 12.6 m fixed lengths. A sawcut would be made every 12.6 m up the length of the stem, i.e. 12.6, 25.2, 37.8 m. As for the 11.1 m cutting pattern it was assumed that merchantable pieces above the last 12.6m length would be extracted and trucked to the central processing yard. I selected 12.6 m for a fixed length cutting pattern since it is about 90% of the 14 m maximum, i.e., less conservative than the 11.1 m pattern.

(c) "fixed" interval cutting zones. The above two cutting patterns are very mechanical and would be easy for a log manufacturer to perform. Most log manufacturers would be able to achieve better value recovery than obtained from those two patterns by making small adjustments, for obvious changes in log quality, above or below the fixed cutting points. In recognition of this the option of making cuts within fixed cutting zones up the stem was included. The cutting zones were located at 10.5 to 13.0 m, 22.0 to 24.5 m and 33.0 to 36.0 m along each stem. As a result of this cutting pattern no piece could exceed 14 m in length.

4.4 DATA ANALYSIS PROCEDURES

The 143 trees used in the data analysis for comparing value recovery at the stump versus on a landing were again used in this study.

4.4.1 Use of AVIS system

The AVIS computer program was used to:

(1) calculate the optimal value that could be obtained from each stem if no fixed length cutting pattern were used. This value was used as a basis for determining the percentage value recovered for each of the three fixed length cutting patterns.

(2) calculate the value that could be obtained from each stem if a fixed length cutting pattern were imposed. One of the features of the AVIS program is the ability to specify "must cut" zones along the stem where the optimisation algorithm has to make saw cuts (Threadgill and Twaddle, 1986). The must-cut-zone feature is usually used to identify portions of the stem which are too swept for particular log types. It can also be used, however, to force cuts to be made at fixed lengths up the stem. The user specifies lower and upper limits for each of the cut zones required. The lower and upper limits are set equal for strictly fixed length options.

The cut zone feature of AVIS proved to be particularly useful for this study. Given the restriction that some cuts have to be made within particular zones the AVIS program calculates the theoretical maximum value that could be obtained under such conditions. A log manufacturer would be expected to achieve slightly less than the theoretical value through either incorrect log measurement with the fixed length cutting patterns or incorrect decision-making with the cutting zone pattern.

4.4.2 Use of spreadsheet templates

Templates were built for use with a micro-computer based spreadsheet program (Symphony) to calculate percentage value recovery and the distribution, by log-type, of volume and value for each of the cutting patterns. The spreadsheet program also proved to be an invaluable aid in data and file manipulation, and data analysis. Sorting of data by cutting pattern and calculation of basic summary and test statistics were done with the spreadsheet.

4.4.3 Statistical analysis

4.4.3.1 Giant Size Regression

A similar approach was adopted for testing hypotheses on differences between cutting patterns to that used in the study described in Chapter 3. Much of the statistical analysis was carried out on a micro-computer using files transferred from the spreadsheets to a program called Number Cruncher Statistical System. The main analysis technique used was Giant Size Regression which was described in section 3.4.3.1.

The regression models used in the statistical analysis for this study were of the form:

$$\hat{Y} = \hat{B}_{11} X_{11} + \hat{B}_{12} X_{12} + \hat{B}_{21} X_{21} + \hat{B}_{22} X_{22} + \hat{B}_{31} X_{31} + \hat{B}_{32} X_{32}$$

$$+ \hat{B}_{41} X_{41} + \hat{B}_{42} X_{42} + \hat{B}_{51} X_{51} + \hat{B}_{52} X_{52}$$

where Y = Percentage value recovery (or NZ$ value recovery).

X_{11} = 1 if fixed length pattern = 11.1 m,

or 0 otherwise.

X_{12} = DBH if fixed length pattern = 11.1 m,

or 0 otherwise.

X_{21} = 1 if fixed length pattern =12.6 m,

or 0 otherwise.

X_{22} = DBH if fixed length pattern = 12.6 m,

or 0 otherwise.

X_{31} = 1 if fixed length pattern = cutting zone,

or 0 otherwise.

X_{32} = DBH if fixed length pattern = cutting zone,

or 0 otherwise.

4.4.3.2 Selection of dependent variables and model assumptions

The model assumptions that form the basis of linear regression analysis were dealt with in a similar way to those in section 3.4.3.2.

Diameter breast height was the independent variable used to differentiate tree size in this study. To linearise the value/DBH relationship two approaches were taken

(1) the dependent variable was transformed by taking the logarithm (base 10) of value (LOGVALF).

(2) a new variable, percentage value recovery, was formed (%RECF). In this study %RECF is calculated in the following manner

$$\%RECF = \frac{100\ (\text{Optimal solution with fixed lengths})}{(\text{Optimal solution without fixed lengths})}$$

Both these transformations also helped to meet the model assumption of constant variance.

If all 143 stems had been used in the GSR for each of the three fixed length cutting patterns the assumption of independency between "independent" variables and beween the data sets would have been violated (see footnote). To overcome this problem stems were selected randomly from the set of 143 to form three subsets of approximately equal size; 47, 48, and 48 stems for the 11.1 m, 12.6 m and cutting zone patterns respectively.

To see what effect this "violation" would have on the conclusions some of the analyses were carried out using the full set of 143 trees as well as the subsets. The conclusions would not have changed.

4.5 RESULTS AND DISCUSSION

4.5.1 Basic recovery statistics

Figure 4-2 shows the average value loss, measured in New Zealand dollars, for the three cutting patterns. Basic recovery statistics for the three cutting patterns are presented in Table 4-2. It can be seen that the average value <u>recovery</u> was lowest for the 11.1 m fixed length cutting pattern and highest for the fixed interval cutting zone pattern.

Table 4-2 Basic recovery statistics

	Recovery ($)		Recovery (%)	
	Mean	Std. Dev.	Mean	Std. Dev.
Optimal	142.86	82.00	100	-
Fixed 11.1 m	133.88	77.91	93.6	3.5
Fixed 12.6 m	134.20	76.26	94.5	3.3
Cutting zone	139.06	80.35	97.3	2.7

Mean percentage value recovery for all three cutting patterns was in the mid-90's. Recovery for individual trees ranged between 80% and 100% as shown in Figures 4-3, 4-4 and 4-5. The cause of outliers, in the low 80% region, was the same for each of the three cutting patterns. High grade peeler material usually extended over the region where fixed length cuts or the

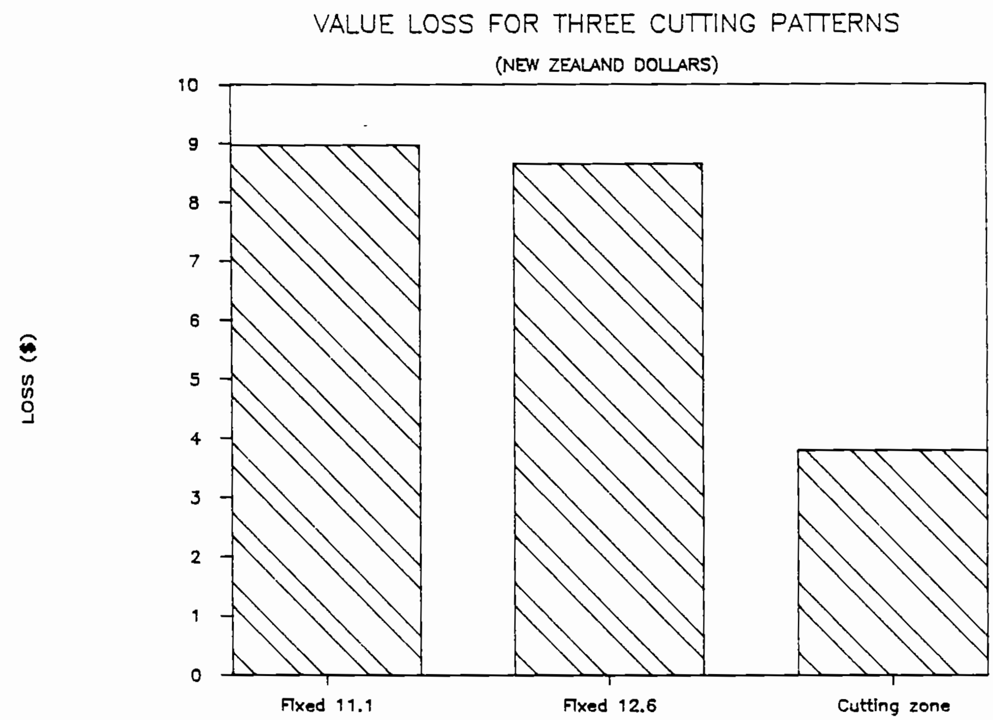


Figure 4-2 Value loss for three "fixed" length cutting patterns.

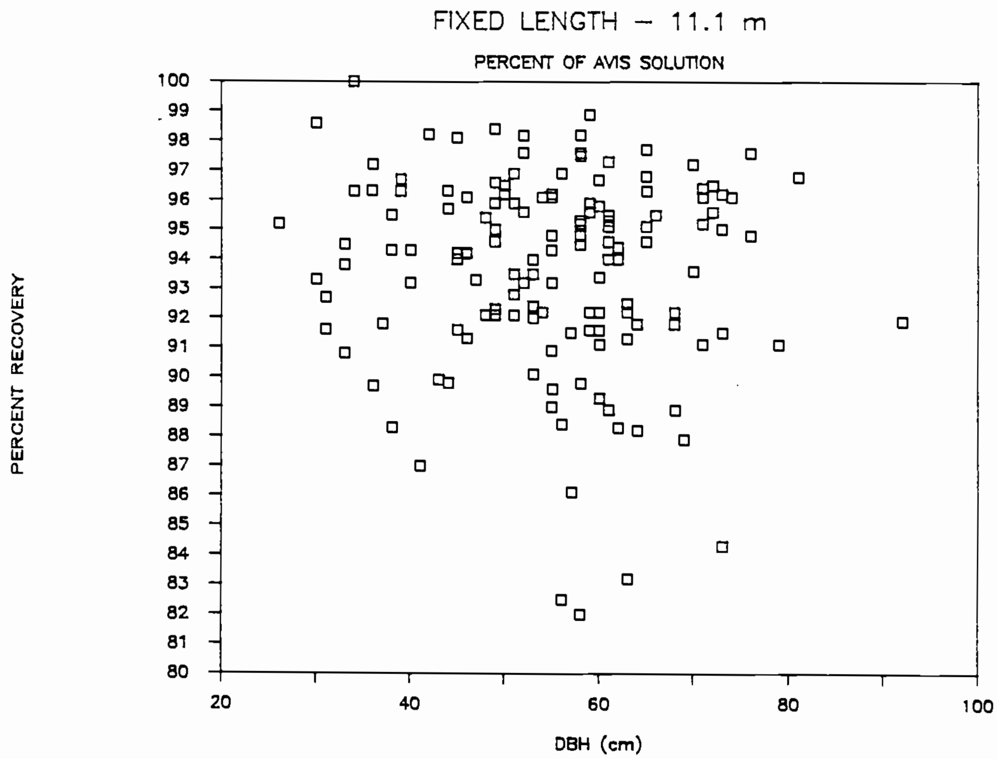


Figure 4-3 Percentage value recovery for a fixed 11.1 m length cutting pattern.

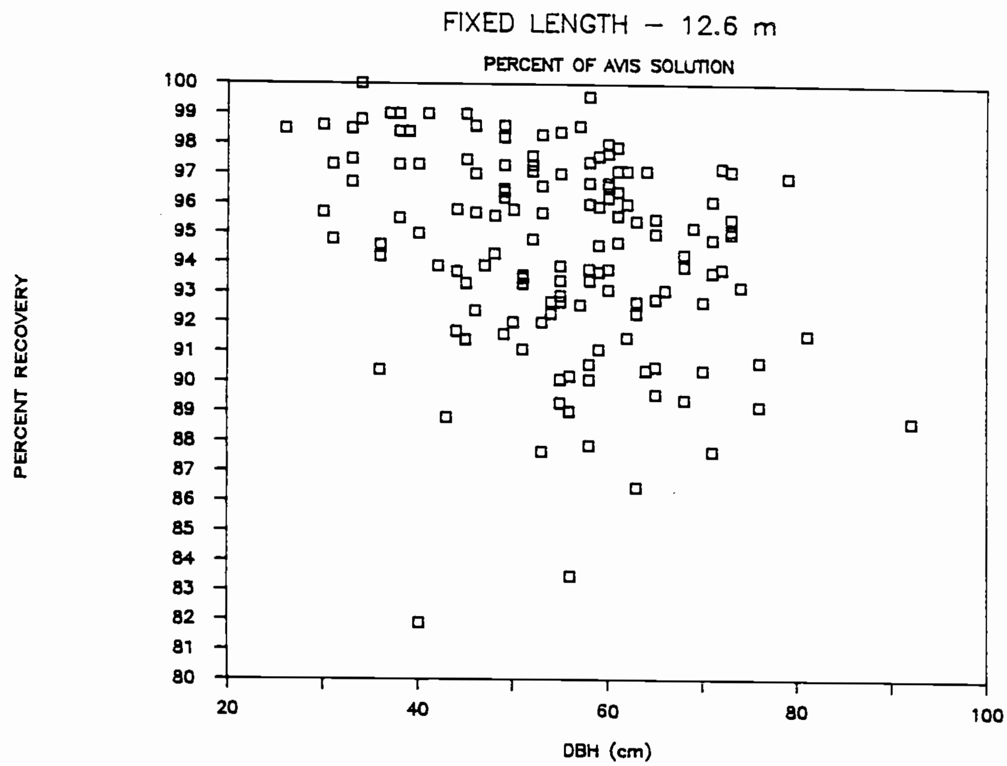


Figure 4-4 Percentage value recovery for a fixed 12.6 m length cutting pattern.

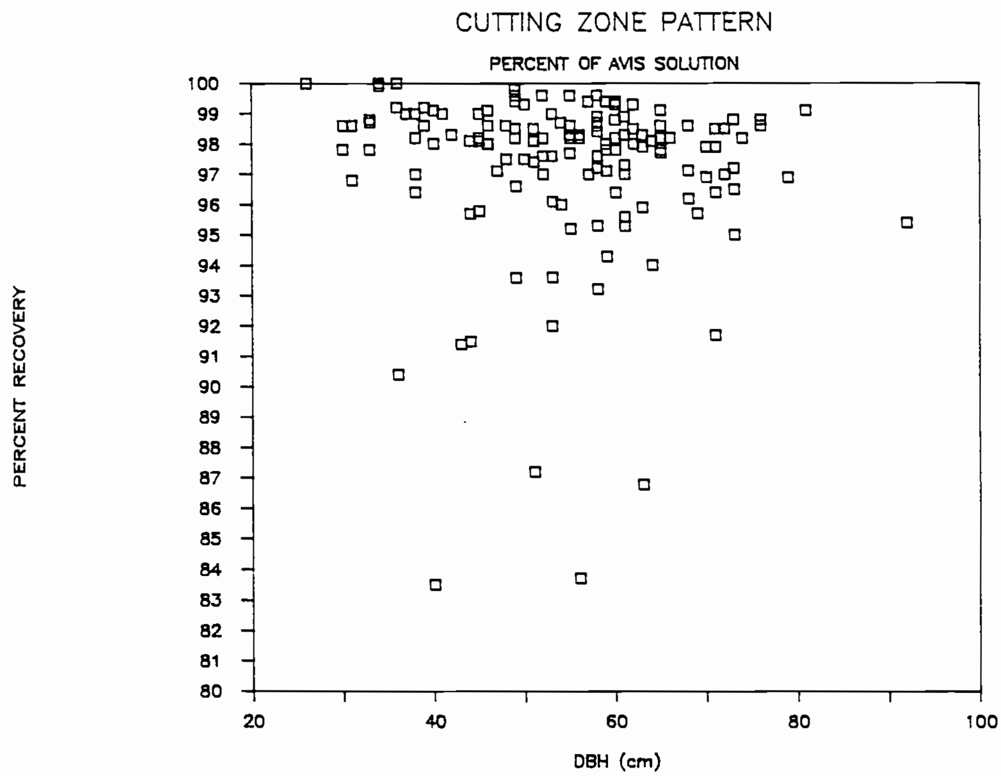


Figure 4-5 Percentage value recovery for a cutting zone pattern.

cutting zone were to be located. As a result of making the cuts, only sawlog or pulp grade logs could be cut from the fixed lengths at the central processing yard.

The large standard deviations for dollar value recovery, resulting from variability in tree size and quality characteristics, makes it difficult to infer from these basic statistics if there are differences between fixed length cutting patterns. Before removing the effects of tree size and quality, paired t-tests indicated that there was no significant difference in value recovery, in dollar or percentage terms, between any of the three cutting patterns. GSR analysis indicated otherwise.

4.5.2 Results of Giant Size Regression Analysis

4.5.2.1 Dollar value recovery

Using the GSR analysis technique it was found that there was no statistical evidence to indicate the need for either separate slopes or separate intercepts for the data sets from the three cutting patterns. The single regression model shown below was found to be adequate for all three cutting patterns.

$$\text{Value (\$)} = 7.184\ e^{(0.05014*DBH)}$$

$$F = 592 \qquad R^2 = 0.808$$

The GSR technique was also used to compare dollar value recovery from the three cutting patterns against the optimal solution for stems without a fixed length cutting pattern. Again no significant difference was found between any of the cutting patterns and the optimal solution. Since the value recovered from the fixed length patterns was in the majority of cases worse than, and at best equal to, that of the optimal solution the difference must exist even though it was not statistically significant. The large variation in stem quality for a given DBH (and thus large variation in dollar value) masks the differences in recovery between the different cutting patterns and between the cutting patterns and the optimal solution.

4.5.2.2 Percentage value recovery

GSR analysis indicated that there was no statistical evidence to suggest the need for separate slopes for the three fixed length cutting patterns. There is statistical evidence to suggest the need for different intercepts, however. Table 4-3 shows the intercept significance matrix for percentage value recovery. With some of the variation in quality removed it can be seen that the differences between cutting patterns now show up as being statistically significant. Cutting stems into fixed lengths of 12.6 m gave significantly different (i.e., higher) recovery than cutting stems into fixed lengths of 11.1 m. Using a cutting pattern which gave more flexibility, by allowing cuts to be made within cutting zones at fixed intervals up the stem, resulted in percentage value recovery which was signficantly higher than both the fixed 11.1 m and fixed 12.6 m cutting patterns.

The results conform to what one would expect. As the fixed length cutting pattern becomes more restrictive potential value recovery decreases. Cutting the stem into smaller lengths but allowing some flexibility in where the cuts were made (i.e., within specified cutting zones) caused a 2.7% reduction in potential value recovery. A further 3 to 4% reduction in potential value resulted from removing the flexibility in where the cuts could be made.

The intercept significance matrix indicates that the data classes can be separated into three regression lines with common slopes as shown in Figure 4-6. It appears that there is a trend for lower <u>percentage</u> recovery with larger stems. Higher grade logs are more

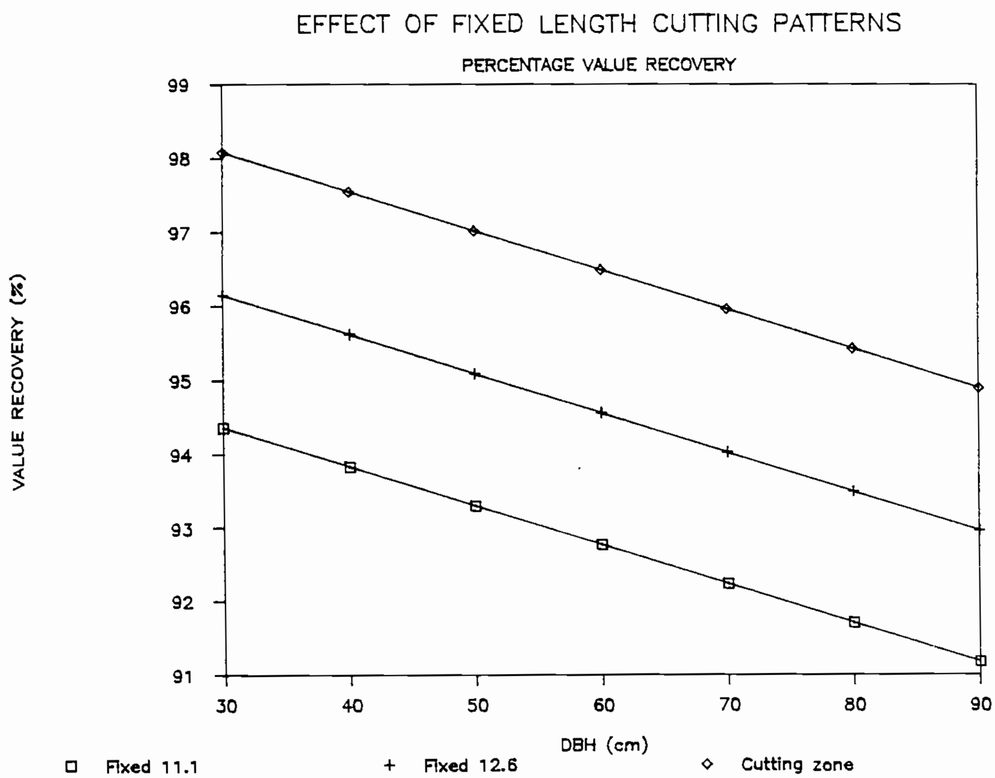


Figure 4-6 Effect of fixed length cutting patterns on percentage value recovery.

likely to be found in larger logs and more value lost because of the application of fixed lengths. The coefficient of multiple determination for the combined regression was very low (0.2), however, so the regression would not be very useful as a predictive tool.

Table 4-3 Intercept Significance Matrix*

	Fixed 11.1	Cutting Zone
Fixed 12.6	**.01**	.01
Cutting Zone	**.001**	

* Note: Figures in this table are probability levels (p-value) that one would have to test at before differences were considered to be significant. Bold figures were considered to be significant by the author (p less than 0.1).

4.5.3 Distribution of volume and value

The percentage of volume that was merchantable for the various cutting patterns was as follows:

- Optimal solution (no fixed lengths) - 98.1%
- Fixed 11.1 m lengths - 95.3%
- Fixed 12.6 m lengths - 94.6%
- Cutting zone - 97.5%

The difference in the amount of volume that was merchantable may account for some of the differences in value recovered but not all. It will be noted that the fixed 12.6 m length cutting pattern had lower merchantable volume, but higher value recovery, than the fixed 11.1 m length cutting pattern. (As an aside this highlights the point that maximising volume recovery is not the same as maximising value recovery).

Figure 4-7 shows the distribution of merchantable volume for the optimal solution and for the fixed length cutting patterns. No 12.3 m fixed length sawlogs could be cut for the 11.1m fixed length cutting pattern since they were longer than allowed by the cutting pattern. The volume of 12.3 m fixed length sawlogs was also substantially less than the optimal solution in the fixed 12.6 m and cutting zone patterns. Much of the fixed length sawlog material was converted into random length long and short sawlogs.

It can be seen that the total amount of peeler material recovered is about 3 to 5% lower for the fixed cutting pattern. There also appears to be a tendency for more shorter length peeler logs to be cut than long length peeler logs for the fixed length cutting patterns.

Figure 4-8 shows the effect that changes in volume distribution have on value distribution. Firstly, it can be seen that there is very little difference in value recovered from short length and long length butt peelers between any of the cutting patterns. This is not

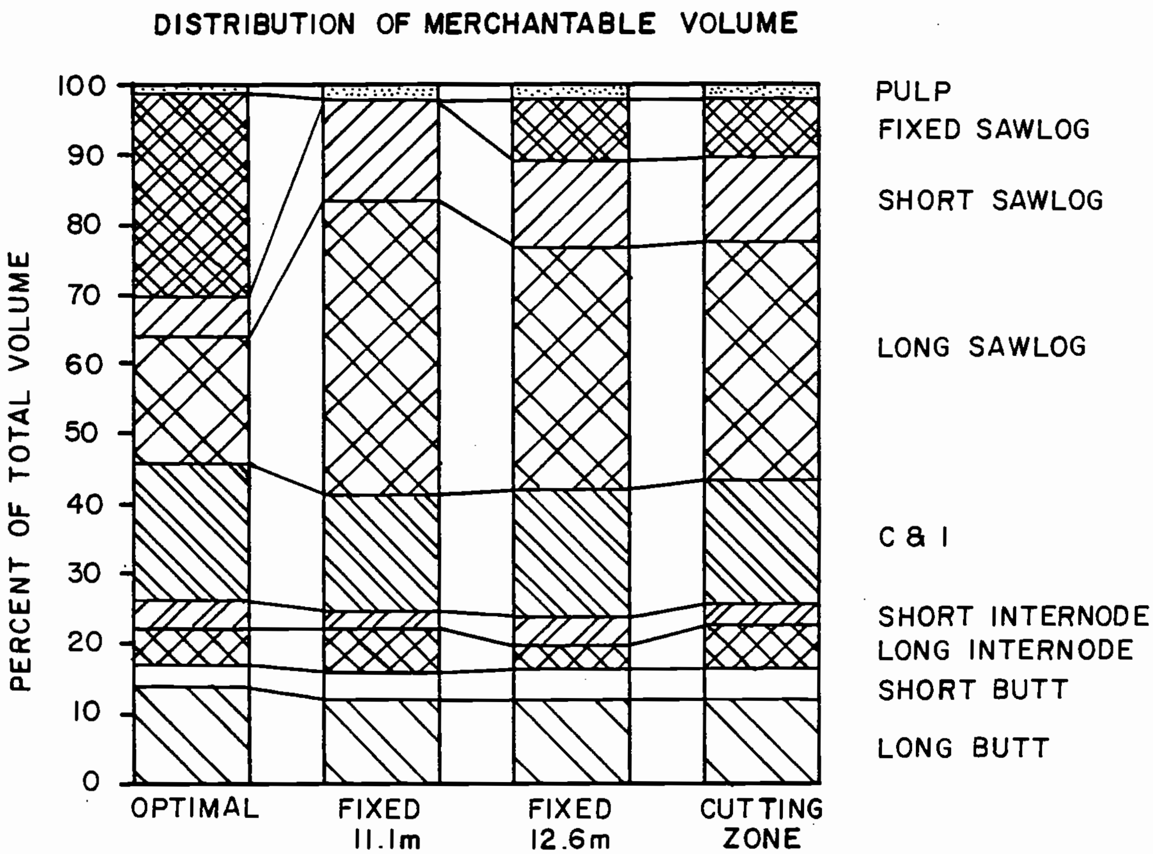


Figure 4-7 Distribution of merchantable volume for three fixed length cutting patterns and the optimal solution.

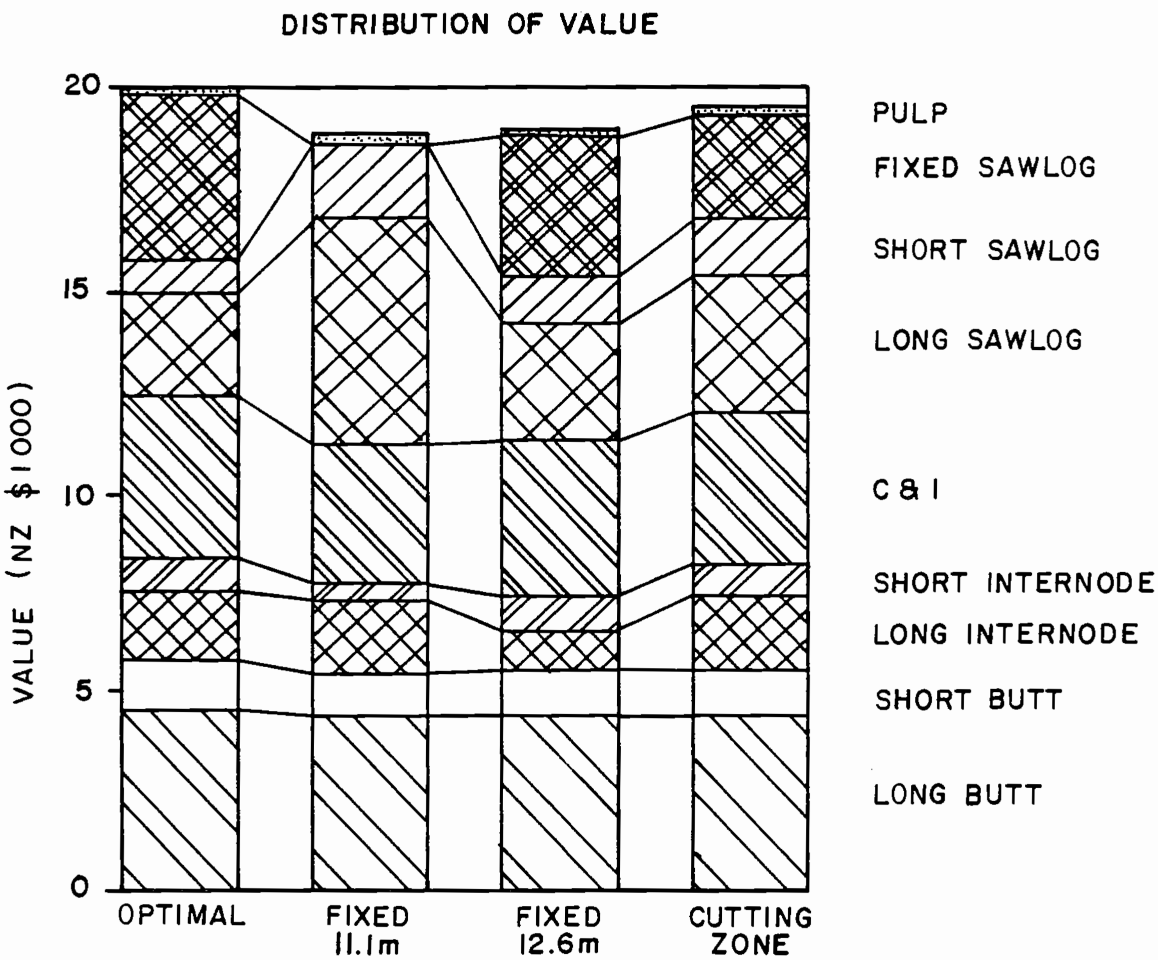


Figure 4-8 Distribution of value for three fixed length cutting patterns and the optimal solution.

unexpected; butt peelers could only be found up to 7 m height on the stem - which was several metres below where fixed cuts were made. The cutting pattern would, therefore, have little effect.

In the optimal solution some internode and C & I peelers extended over the 10 to 13 m zone. These logs were "lost" when the fixed length cutting patterns were applied. The drop in value is noticeable.

Although there is considerable difference in the value recovered in 12.3 m fixed length sawlogs between the optimal solution and the fixed length cutting patterns, particularly the fixed 11.1 m cutting pattern, the overall effect on total value recovery is not large. As mentioned above, much of the fixed length sawlog material was converted to random length sawlog material. There was only a $2.00 per cubic metre premium for fixed length sawlogs over random length sawlogs. The worst percentage value loss that the conversion to random lengths could account for is about 1% for the fixed 11.1 m length cutting pattern.

4.6 CONCLUSIONS

Before drawing conclusions from this study it is again necessary to stress some of the warnings given in the conclusion section (3.6) of the previous chapter. This study was carried out in a single stand, using only one set of log specifications, and one set of log prices. Additionally the value recovery referred to, from cutting fixed lengths at the stump and then transporting these lengths to a central processing yard for further log manufacturing, is a **potential** recovery and not actual recovery. Potential value recovery was calculated assuming that all fixed length cuts were accurately made at the stump and that resulting lengths were further processed in a completely optimal manner at the central processing yard. It can be expected that actual value recovery at a central processing yard would be less (how much less is unknown) than the potential value recovery.

The main results and conclusions of this study can now be summarised as follows:

(1) In terms of objective 1 it was found that the mean potential value recovery for the three fixed length cutting patterns was in the mid-ninety percent range. Recovery for individual trees ranged between 80% and 100%

(2) In terms of objective 2 it was found that there was no statistical evidence to indicate differences in dollar value recovery existed between the three cutting patterns. The large variation in stem quality for a given DBH (and thus large variation in dollar value) masked the differences in recovery between the different cutting patterns and between the cutting patterns and the optimal solution.

(3) However, when some of the variation in quality for a given DBH was removed it was found that:

- cutting stems into fixed lengths of 12.6 m gave significantly different (i.e., higher) percentage value recovery than cutting stems into fixed lengths of 11.1 m. The difference, although being statisticaly significant, was relatively small.

- using a cutting pattern which gave more flexibility, by allowing cuts to be made within cutting zones at fixed intervals up the stem, resulted in percentage value recovery which was significantly higher than both the fixed 11.1 m and fixed 12.6 m cutting patterns.

(4) The percentage of volume that was unmerchantable for the fixed length cutting patterns was two to three times that for a cutting pattern where no fixed lengths were super-imposed. The highest percentage of volume that was unmerchantable was 5.4%.

(5) Most of the reduction in value for the fixed length cutting patterns can be attributed to an overall reduction in the amount of peeler volume cut and a redistribution of the volume from long length peeler logs to short length peeler logs.

The potential value recovery reported here is about 10% to 20% greater than reported in the previous chapter for actual value recovery when logs were manufactured at the stump. If all the potential recovery could be realised at a central processing yard this would appear to be a viable alternative to manufacturing stems into final log lengths at the stump.

The potential value recovery is also about 10% greater than reported in the previous chapter for actual value recovery on a landing, but only about 5% greater than Twaddle (1985) considered that log manufacturers could achieve on a landing given the right tools and committment to maximising value recovery by management. The reduction from potential to actual value recovery at a central processing yard may result in very little difference between these two log manufacturing locations. These issues will be dealt with in more detail in Chapter 6.

4.7 RECOMMENDATIONS FOR FUTURE RESEARCH

I see three main areas for future research on value recovery at central processing yards.

(1) This study should be repeated for more forest stands on steep country which have received intensive silvicultural treatment and are representative of those to be harvested in the near future. The findings of this study were limited by the analysis only being carried out for one stand. Although the magnitude of the value recovery is likely to be similar greater confidence in the results of this study should be gained.

(2) Long lengths and, in particular, premiums paid for long fixed length logs of higher grades are likely to have a large effect on percentage value recovery. Other sets of typical log specifications and prices should be used to quantify the effect these have on potential value recovery.

(3) There is a great paucity in the literature of studies carried out on actual value recovery in central processing yards. Central processing yards usually require a high capital investment. Since their purpose is to recover the maximum value (at the least cost) from manufacturing logs out of stems or truck lengths it is

essential that a better quantification of value recovery, and an understanding of the factors affecting value recovery, be obtained. It is recommended that actual value recovery in a central processing yard be studied. There are currently no fully operational central processing yards in New Zealand. Without establishing a central processing yard this recommendation may be difficult to accomplish within New Zealand.

CHAPTER 5. THE EFFECT OF FINAL LOG MANUFACTURING LOCATION ON STEEP COUNTRY HARVESTING PRODUCTIVITY AND COSTS.

ABSTRACT

The trend towards harvesting steeper and more difficult terrain in New Zealand's radiata pine plantations has caused many logging managers to wonder what effect alternative locations for final log manufacturing might have on yarding productivity and costs. To answer this question a processing options simulation model (PROSIM) was constructed. PROSIM was found to be a quick and inexpensive method to evaluate many system alternatives on the basis of yarding productivity and stump-to-milldoor costs.

Three main locations for final log manufacturing were evaluated: at the stump, on a large landing, and at a central processing yard. The effect of various bucking alternatives, yarding systems, and terrain conditions were examined for each of the possible locations.

Based on assumed costs and productivity, it was concluded that, where possible, large landings and large yarders should continue to be used. If the terrain, soil

conditions, or other environmental considerations preclude the use of large landings then the next best alternative is to carry out the final log manufacture at the stump and yard to small landings or roadside. Smaller yarders with fast line speeds may be the most viable machine-type if small landings have to be used. Final log manufacture at a central processing yard would be the least preferred option.

Use of the PROSIM model highlighted areas where future research would be particularly productive.

5.1 INTRODUCTION

As stated in Chapter 1, some of the reasons for looking at alternative locations for final log manufacturing are related to concerns about environmental issues, land taken out of production by large landings, improving value recovery and product utilisation, reducing interference between system components, increasing productivity and reducing costs. The previous three chapters have been concerned with the effect of final log manufacturing location on value recovery. Most logging managers are more concerned with the effect that log manufacturing location could have on harvesting productivity and costs. This chapter examines the effects of final log manufacturing location on cable yarding productivity and stump-to-milldoor costs.

Bucking at the stump has been proffered in New Zealand by some people as the means to increase yarder productivity and reduce costs. Claims of 500 to 700 logs reaching the landing per day have been made for this logging system (Spiers, 1978). Cottell and others (1976), reporting the results of a detailed study on cable-logging operations in British Columbia where both tree-length and log-length extraction were carried out, state that "it is unusual for any cable machine to <u>average</u> more than 220 pieces per [day] shift"; 100 to 150 pieces per shift is common. New Zealand should not expect huge increases in productivity and large reductions in costs _if_ alternative systems are adopted.

In the Pacific Northwest of America it is common practice on steep country clearfell operations to buck at the stump, because of the very large trees being harvested. In thinning operations it is more common to extract treelength logs, because of the small trees being harvested. Conway (1982), and many other authors, have shown that logging costs increase exponentially as piece size decreases. This piece size cost curve is sometimes called a "reverse-J" curve because of its shape. A more thorough analysis of the piece-size cost relationship would show that the curve is really "U-shaped" (Figure 5-1). As piece size gets too large a point is reached where existing machinery cannot handle even a single piece. Bigger and more expensive machinery has to be used. Practical limits are eventually reached (although one must wonder where the limits exist when some loggers have built 80 metre towers and converted crawler tractors into extremely large carriages (Robinson, 1978)). A reverse-J curve indicates that costs can always be reduced by increasing piece size. A U-shaped curve indicates that there is an optimum piece size. The point

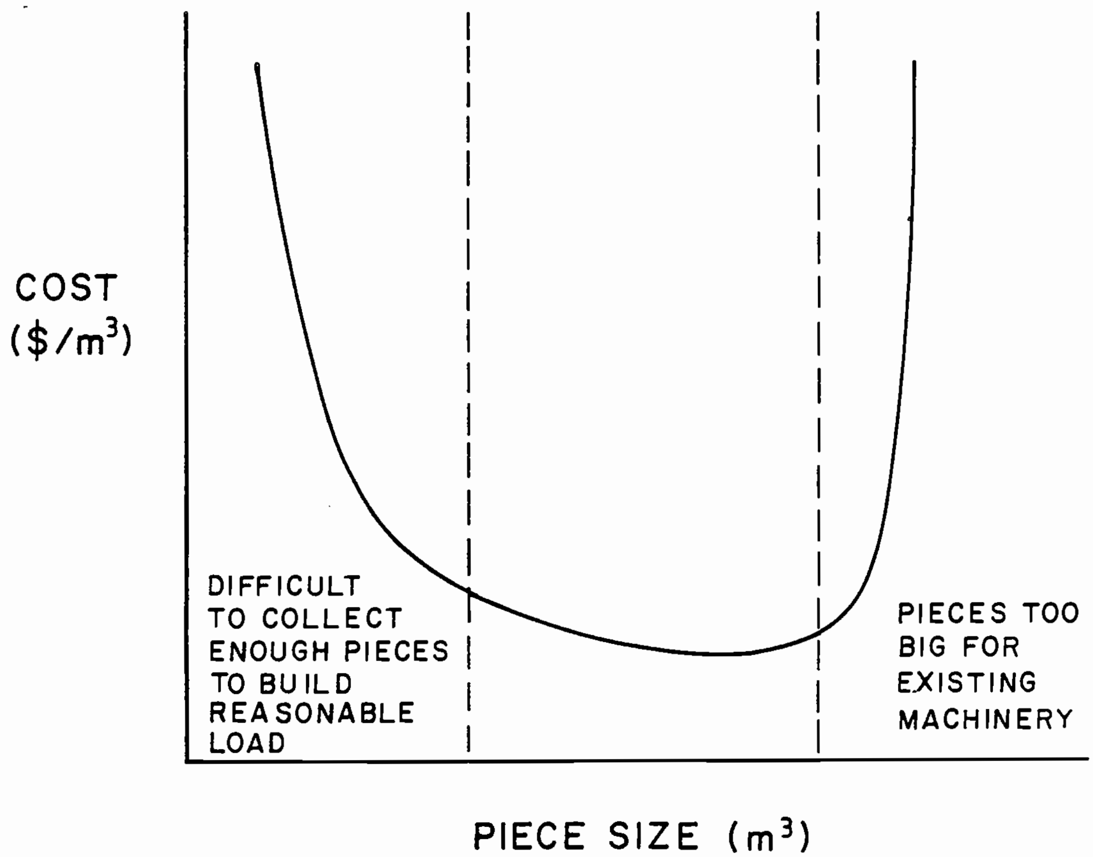


Figure 5-1 U-shaped harvesting cost curve.

of view that one takes as to which logging system is best depends on which side of the U-shaped curve the tree size of the forests to be harvested lies.

Conway (1982) has pointed to an emerging trend, in the Pacific Northwest, of more "multiple length and tree-length logging, where applicable," as tree-size becomes smaller. Owens (1971) and Cottell and Sauder (1985) have pointed to similar trends in Canada. Cottel and Sauder have suggested that such a move would allow piece size to be maximised, bucking decisions to be reserved until later in the sequence of processes, and reduced labour consumption in the stump area.

Researchers at Oregon State University have been investigating techniques for improving smallwood harvesting productivity for over a decade now. Putnam and others (1984) described a study in a regenerated Douglas fir stand that was carried out to compare production rates and costs of whole-tree, tree-length, and log-length skyline thinning where tree size removed was about 0.46 cubic metres. They found that tree-length and whole-tree thinning resulted in higher yarder productivity (about 6% increase) and lower total stump-to-truck costs (about 13% decrease) than the log-length system. They also noted that "although the limbing and bucking process is not eliminated with the whole-tree system, its efficiency is greatly improved by transferring the operation to the landing area. Not only are the tasks of limbing and bucking more productive in a prepared area, but a large number of limbs are broken off during the yarding operation."* They also suggested that whole-tree and tree-length yarding methods should not be confined to thinning operations, since they are also applicable to clearcutting second-growth stands.

Several system trials have been carried out in cable-thinning radiata pine plantations in New Zealand. Murphy (1979b, 1982b) described comparative trials with the Timbermaster skyline yarder. In a tree-length trial, where the mean log volume removed was 0.34 cubic metres, daily production averaged 32 cubic metres. When the trees were cut into short lengths and manually carried to the extraction corridor daily productivity rose to 56 cubic metres. The crew size, including fallers, increased from 5 to 10 men, however. The short length method was understandably abandoned because the fallers were not prepared to work with this method without a considerable wage premium.

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* Many branches break off during yarding of radiata pine also. Not all tree species have this characteristic.

In 1979 McConchie carried out a comparison of tree-length and log-length (up to 9.2 metre maximum) thinning with the prototype Lotus skyline yarder in New Zealand. The stand was 17 years old at the time of thinning and the average tree size was about 0.4 cubic metres. Average daily production was about 17% greater with the tree-length system than the log-length system; 48.7 cubic metres per day and 41.7 cubic metres per day, respectively. This occurred despite a larger number of pieces being hooked per turn for the log-length system.

Overall, cable thinning is of minor importance to New Zealand. Most of our wood will come from clearfelling operations. It is estimated that less than 2% of future harvest volumes will come from cable-thinned plantations (Murphy, 1982).

Clark (1986) found that tree-length logging of lodgepole pine and spruce stands in the British Columbia Cariboo region resulted in a 10% reduction in stump-to-mill door costs when compared with conventional systems. The operation studied was a flat country mechanised system. Peterson (1986) has stated that to remain profitable the forest industry of British Columbia is introducing more productive harvesting and processing methods such as full-tree yarding, woods sorting of logs to allow direct end-destination transportation, manual processing to optimise log manufacture, and manual felling without delimbing or bucking to increase felling productivity. Peterson reports that discussions with logging personnel indicate at least a 30% increase in yarding productivity with tree-length versus log-length systems.

Wipperman (1984) and Grammel (1984), on the other hand, report increases in costs in Europe, rather than a reduction, when full-tree systems are used instead of log-length systems.

Alternative log manufacturing systems have also been investigated on a limited basis for clearfell operations in New Zealand. Using elemental time study data three systems of log preparation were looked at for harvesting a radiata pine stand (1.42 cubic metres average tree size) with a Madill 009 yarder (Murphy, 1978c). Tree-length logging was found to be approximately 45% more productive than the best log-length system analysed and stump-to-truck costs were approximately 32% lower. The optimistic assumption was made in the analysis of the best log-length system that an average of 8 pieces per cycle would arrive at the landing.

A comparative field study of tree-length and log-length extraction with a Washington 88 yarder was also carried out recently in New Zealand. Because of problems with the study design and analysis the results remain preliminary and are unlikely to be published. It was found, however, that average daily production was about 9% higher for the log-length system. In this trial the average tree size (4.8 cubic metres) was considered to be too big for the Washington 88 yarder without some reduction in piece size.

Although some preliminary trials have been carried out in New Zealand further detailed experimental design, analysis, and field trials still need to take place.

5.2 STUDY OBJECTIVES AND HYPOTHESIS

Steep country harvesting is generally considered to be from 1.5 to over two times as expensive as flat country harvesting for the same tree size (Cottell et al., 1976; Terlesk, 1980). If plantation forestry is to be profitable on New Zealand's steep terrain it is important that productivity be kept as high as possible and costs as low as possible. Costs should be looked at on system level, if at all possible.

New Zealand has very little experience with log manufacturing systems for clearfell steep terrain harvesting other than tree-length systems. It is necessary to address this situation on an analytical level, and with field oriented trials as soon as possible.

The objectives of this study are:

(1) to develop a procedure for evaluating steep country harvesting systems on a total system cost basis,
(2) to determine if there are any differences in system costs when final log manufacturing is carried out in various locations,

(3) to determine the sensitivity of the costs to changes in the assumptions required to carry out the analyses, and

(4) to identify deficiencies in the data base used for the system analyses.

The number of logging systems that could be evaluated for this study is infinite when one considers the possible combinations of stand conditions, yarders, loaders, manpower structure, bucking patterns, log manufacturing location, trucking haul distances, central processing yard size, and so on. This study will be restricted, however, to examining only a few combinations of these. Figure 5-2 shows the broad systems to be analysed. Further description of individual components of each system can be found in sections 5.7 and Appendix B. All analysis will be carried out using stand and piece size data derived from the log value recovery study described in Chapter 3.

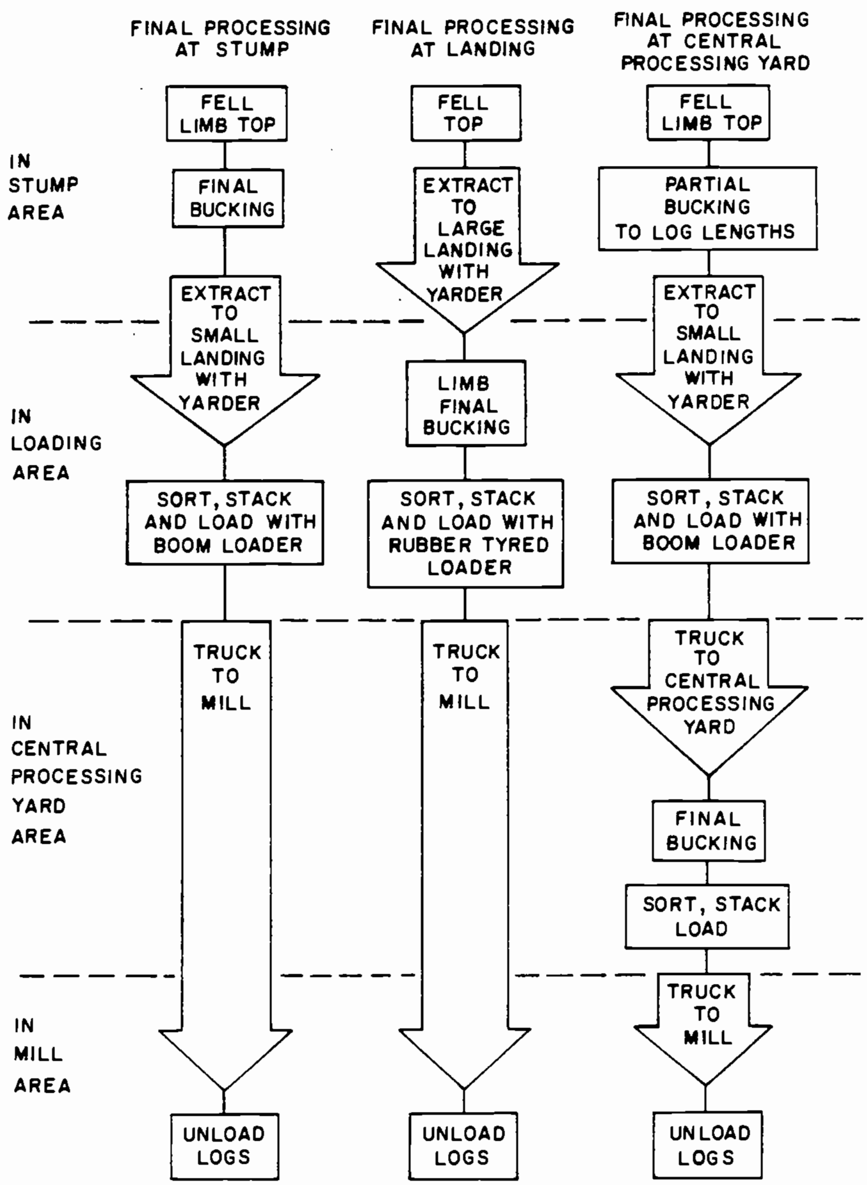

Figure 5-2 Harvesting systems analysed.

The specific hypothesis to be tested by this study is:

There is no significant difference in total stump-to-milldoor system costs when logs are manufactured into their final form at

(i) the stump,

(ii) the landing, or

(iii) a central processing yard.

5.3 EXPERIMENTAL DESIGN

To reiterate what was stated in section 5.2, the main objective of this study was to see if there were significant differences in steep country harvesting system costs when logs were manufactured into their final form at one of three locations; at the stump, on a landing, or at a central processing yard. It was thought that the results might be sensitive to the size and type of yarder used to extract timber from the harvest unit. A two-factorial, randomised block experimental design was selected for the study (Peterson, 1985). The two factors in the design would be log manufacturing location and yarder type. Different harvesting units would represent the blocking (or replication) feature of the design. Simulation was considered to be the best approach for evaluating costs for the various harvesting systems (see section 5.4).

The three yarder types used in the analysis are discussed in more detail in Appendix B. They are:

- a Madill 009 rigged as a Grabinski skyline system,
- a Madill 071 rigged as a slack skyline system, and
- a Washington 88 rigged as running skyline system.

The Madill 009 is the most common yarder in New Zealand and is frequently rigged as a Grabinski system.

It is a 2-drum, 335 kW yarder mounted on a rubber-tyred or tracked undercarriage.

There are only a few Madill 071 yarders in the country. They are rigged in a range of configurations. The Madill 071 is a 4-drum, 215 kW yarder mounted on a tracked undercarriage.

There are only two Washington 88 yarders in New Zealand. They are used as running skyline systems. The Washington 88 is a 3-drum mechanical interlocked yarder mounted on a tracked undercarriage. It is powered by a 230 kW motor.

It was decided to include six log manufacturing patterns in the experimental design; three at the stump, one at the landing, and two at a central processing yard. Short descriptions of these patterns follows:

(1) AVIS optimal - this bucking pattern assumes that the faller has a handheld computer with him at the stump, which suggests the optimal way to buck the stem to get the most value out of it. The distribution of logs generated by the AVIS program as part of the output from the study reported in Chapter 3 represented the "AVIS optimal" pattern. The log distribution was used in the analysis.

(2) Solly - in Chapter 3 it was reported that there was no significant difference in value recovered by

Solly (the best log manufacturer studied) at the stump versus on a landing. The distribution of logs generated by Solly was used as a distinctive bucking pattern.

(3) Solly, Dick, and Jim - the three log manufacturers studied and reported in Chapter 3 could be classified as representative of a broad cross-section of log manufacturers in New Zealand. All logs generated during log manufacturing at the stump by these three workers were lumped into a single log distribution as a representative bucking pattern.

(4) Tree-length - the tree-lengths extracted to the landing during the value recovery study reported in Chapter 3 were representative of the tree-length bucking pattern. Trees were processed into logs on the landing.

(5) Fixed 12.6 m. - several bucking patterns that might be applicable to final manufacturing of logs at a central processing yard were described in Chapter 4. One of these was cutting stems into fixed lengths of 12.6 metres at the stump. The logs from the AVIS output for the value recovery analysis were used to generate a representative log distribution for this cutting pattern.

(6) Butt 12.6 m. - a bucking pattern not considered in Chapter 4 was to cut a 12.6 metre butt log from each stem at the stump. The average piece size would be smaller than for tree-length extraction and a large

landing would probably not be required. The AVIS output used to generate the Fixed 12.6 m. bucking pattern was modified to represent this bucking pattern.

Four harvest units were selected for replication as blocks in the design; two harvest units were located on U.S. Forest Service land in western Oregon, and two were located in Whakarewarewa State Forest Park, New Zealand. The harvest units were of different size, shape, and terrain. Figures 5-3, 5-4, 5-5, and 5-6 show the portions of the topographical maps used to generate the digital terrain models on which the harvest units were located. The harvest units were named, and will be referred to hereafter in this chapter, as USA1, USA2, NZ1, and NZ2. All material trucked was less than 14m in length.

The experimental design was a complete factorial design, that is, all combinations of treatments were replicated on each block. Each simulation run represented a combination of one yarder, one bucking pattern, and one harvest unit. Several simulation runs were completed for each combination for reasons described in the next section. A total of 72 lots (3 machines X 6 bucking patterns X 4 harvest units) of simulations were carried out for the analysis.

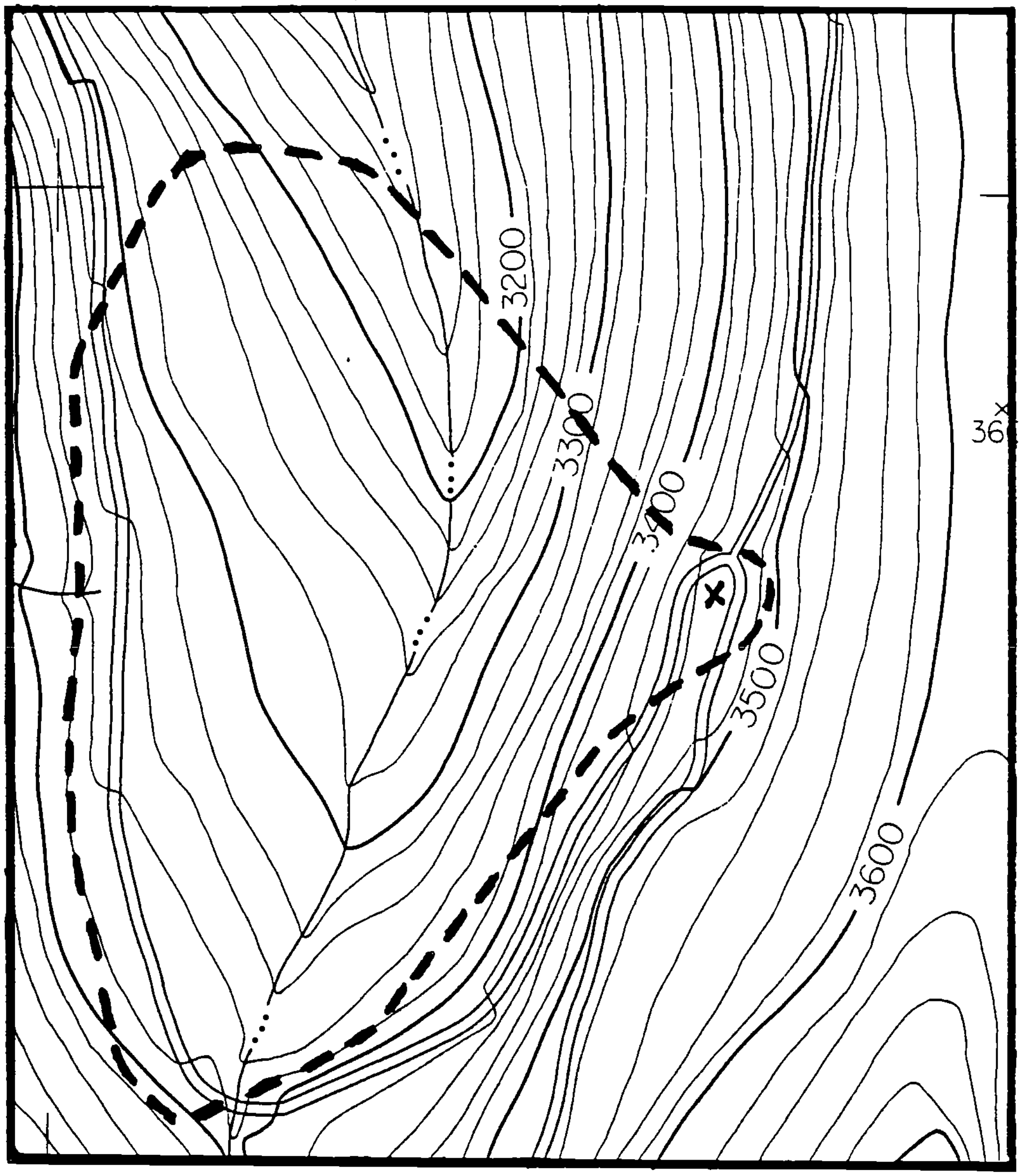

Figure 5-3 Topographic map of USA1 harvest unit.
Scale = 1:9300. 20 foot contours.
Area = 9.4 hectares. X = landing.

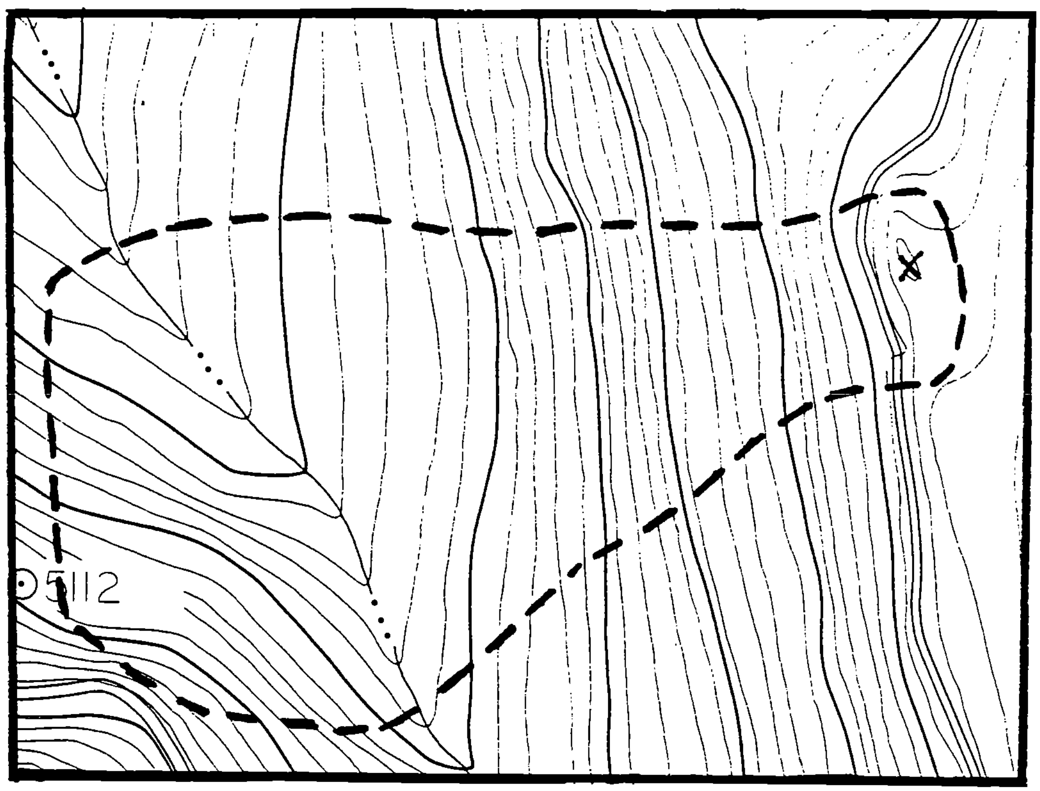

Figure 5-4 Topographic map of USA2 harvest unit. Scale = 1:9300. 20 foot contours. Area = 7.2 hectares. X = landing.

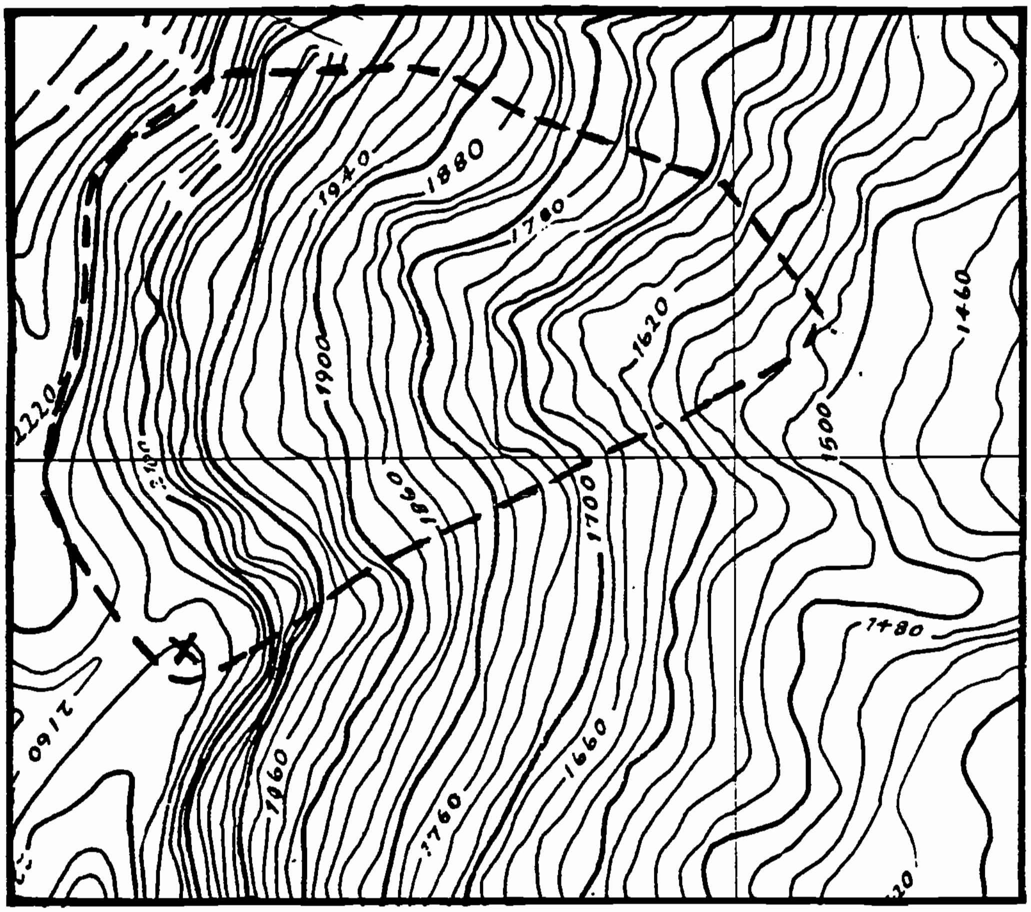

Figure 5-5 Topographic map of NZ1 harvest unit. Scale = 1:10000. 20 foot contours. Area = 8.3 hectares. X = landing.

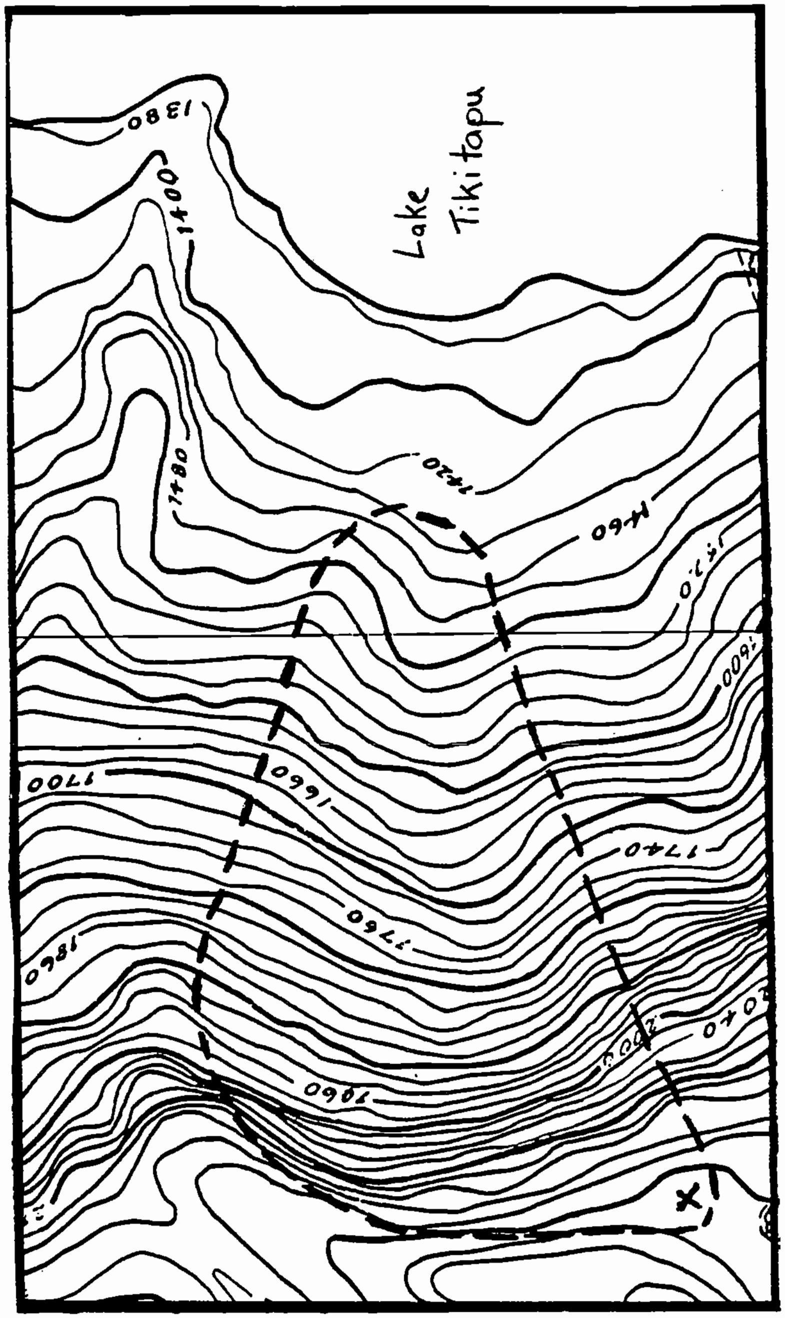

Figure 5-6 Topographic map of NZ2 harvest unit. Scale = 1:10000. 20 foot contours. Area = 6.2 hectares. X = landing.

5.4 SIMULATION AS AN APPROACH TO EVALUATING SYSTEM COSTS

The use of simulation in the forest industry is not new. The breadth of use ranges from individual tree growth models (Wykoff and others, 1982), through log bucking decision simulators (Lembersky and Chi, 1984), and up to seedling-to-sawmill economic models (Whiteside and Sutton, 1983). In the past two to three decades the use of simulation models has found wider acceptance and application in the harvesting sector of the forest industry. Simulation allows the comparison of alternative operations without the expense of large field trials. When designing systems for particular applications many poor alternatives can be eliminated from consideration and promising alternatives quickly highlighted if good simulation models are available.

There is no universal harvesting simulation model available that would answer all harvesting questions. This is because harvesting systems and the environment in which they operate are exceedingly complex. Goulet and others (1979), in their review of tree-to-mill forest harvesting simulation models, indentified the Harvesting System Simulator (HSS) (O'Hearn et al., 1976) as being probably the most complex harvesting model found. They believed it contained the potential for modeling most [but not all] harvesting configurations.

No consensus exists on what constitutes a harvesting model's essential elements. The level of detail included in a model generally reflects the modeler's point of view. For example a modeler working in the relatively flat plantation forests of the southern United States is likely to have a different perspective of the essential elements to a modeler working in the steep terrain of the Pacific Northwest of America, or to a modeller working in the jungles of Papua-New Guinea.

Many harvesting simulations have concentrated on modelling forest operations on gentle terrain, primarily in eastern Canada or the southeastern United States. In these areas ground skidding methods are usually used. Models, such as Timber Harvest and Transport Simulator (THATS) (Martin, 1973), HSS (O'Hearn et al., 1976), Simulation Applied to Logging Systems (SAPLOS) (Johnson et al, 1972), and LOGCOST (Giles, 1986), are examples of ground skidding simulators.

Mechanised harvesting systems have also received some attention from modellers in the northcentral United States (Winsauer, 1980; Winsauer and Bradley, 1982; Bradley, 1984).

In recent years attention has also been given to modelling cable-logging systems on steep terrain. Significant work has been carried out by Johnson and others (1972), O'Hearn and others (1976), Dykstra and Riggs (1977), Sessions (1979), LeDoux (1981), Gibson and others (1983), Twito and McGaughey (1984) and Giles (1986). The THIN model, in particular, has seen wide use by its author for addressing a range of questions related to cable-thinning (LeDoux, 1981; 1982; 1984a and 1984b; 1986). Some of these models were reviewed for their ability to answer the questions posed by this study. Each had limitations which precluded their use and resulted in a new model PROSIM (Processing Options Simulation) being written to address the hypothesis put forward. It is not my intention to point out the deficiencies (from this modeller's perspective) in the other cable-logging models. The reader, who is familiar with some of these other models, should be able to recognise the limitations. A quick review of some of the features which were desired and incorporated in PROSIM should highlight where PROSIM differs from other models.

Murphy (1979a) pointed out that yarding is the most expensive phase of stump-to-truck cable logging operations in New Zealand. Sauder and Nagy (1977) found that yarding costs represented the highest cost component of stump-to-milldoor (including road access) harvesting costs in the steep terrain of British Columbia. It is essential that the yarding phase be modelled in detail.

Peters (1973) was among the first in the literature to identify skyline payload capability, log density and distribution per unit area, and log size as three of the primary elements in determining skyline loadings and production. Some of the other models have the user input an average which pertains to the whole harvest unit. Terrain and yarder mechanics generally determine skyline payload capability which can vary considerably over a harvest setting. It was considered essential that terrain (on entire harvest settings) and cable and yarder mechanics be modelled in detail.

The size and distribution of logs on a harvest setting are dependent on the bucking pattern used. Many of the models assume a homogeneous log product or, if a log bucking simulator is included in the model, all stems are cut into a single fixed-length. Many log products are cut from New Zealand's radiata pine plantations. It was considered essential that the model be able to simulate harvesting of logs cut using multi-product bucking patterns.

Most of the steep country logging in New Zealand incorporates extraction of timber from irregular shaped settings to a central landing. The model should be able to simulate this extraction method.

To compare the effect of final log manufacturing location on costs it is necessary to take a systems approach to the problem and have common starting and ending points for each alternative. It was decided that the model should be able to start with landing construction and finish with logs being unloaded at the milldoor.

5.5 "PROSIM" MODEL OVERVIEW

The Processing Options Simulation model (PROSIM) was put together with two thoughts in mind:

(1) It had to provide data so that the hypothesis formulated in section 5.2 of this chapter might be tested, and

(2) It might be adapted sometime in the future to be a harvest planning and management tool.

This section of the chapter provides an overview of the model. Appendix B gives detailed descriptions of each of the components of the model. The complete computer program listing for the PROSIM model can be found in Appendix A.

PROSIM is a part stochastic/part deterministic simulation model which provides stump-to-milldoor harvesting costs as its main output. Log size generation and location are the only stochastic portions of the model. PROSIM does not model interactions between phases of the harvesting operation. All inputs to and outputs from the model are in metric units. PROSIM is written in HP-BASIC and runs on a Hewlett Packard 9020 computer with a Calcomp 9000 digitizing tablet and Hewlett Packard 2930 series printer as peripherals. Figure 5-7 shows a

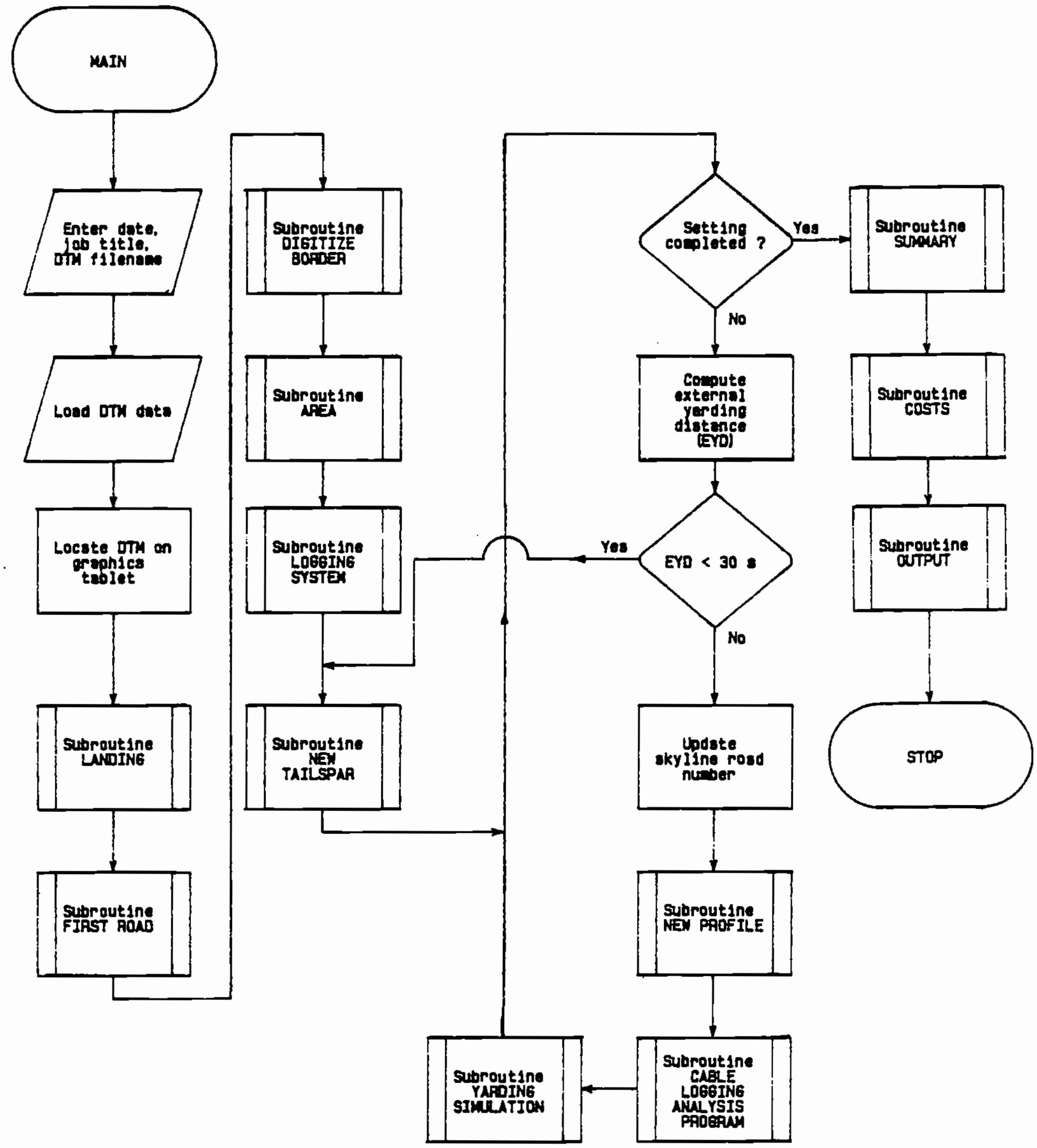

Figure 5-7 Flowchart of overall PROSIM model.

```
============================
PROCESSING OPTIONS SIMULATION
============================

USA1_009_E1                                          26_January_1987


System information
==================

Log processing partially carried out at the stump and then completed at a
Central Processing Yard.
Yarding machine was a Madill 009 rigged as a Grabinski skyline.
Loading was with a medium-sized hydraulic boom loader.

Stand and setting information
=============================

Mean diameter breast height (cm) =       55.0
Stocking (stems per hectare)     =       200.0
Mean tree volume (cubic metres)  =       3.1
Live stand volume (m^3/ha)       =       620.0
Pungas per hectare               =       300.0

The setting was irregular shaped and was   9.4 hectares in area.



Yarding and cycle statistics
============================

Daily yarding production was 194.5 cubic metres.
It took  29.2 days to harvest the setting.
The number of skyline road changes was   46.0
The number of yarding cycles was         1334.0
The average log weight was  1239.3 kilograms
 39 logs (totalling   89.0 cubic metres) were too big to be yarded uncut.
The average yarding distance was 198.4 metres.
Total volume extracted was   5671.4 cubic metres.


                              Mean     Std dev   Minimum   Maximum


      Cycle volume (m^3)      4.25      2.38       .02      13.56
      Number of logs          3.43      1.54      1.00       6.00
      Cycle time    (Min)     6.45      1.06      3.93       8.49
```

Figure 5-8   Sample output from PROSIM model.

===========================
PROCESSING OPTIONS SIMULATION
===========================

USA1_009_E1 26_January_1987

Trucking information
====================

One-way lead distance for ALL logs was
30.0 kilometres.
100.0 % of the total volume was trucked as this product type.

Cost information
================

	Setting	Hectare	Cubic metre
Falling	7546	799	1.33
Yarding	91953	9731	16.21
Processing	3587	380	.63
Loading	37614	3980	6.63
Trucking	50779	5374	8.95
Sortyard	41118	4351	7.25
Move in/Move out	3619	383	.64
Landing Construction	2500	265	.44
Total	238715	25262	42.09

Figure 5-8 Sample output from PROSIM model. (continued).

flowchart depicting the overall structure of the model. As can be seen the model is comprised of many subroutines. Figure 5-8 shows sample outputs from the model which should make some of the latter description easier to follow.

PROSIM is used in the following manner:

Step 1. Prior to running the model a digital terrain model (DTM) containing the harvest unit areas to be used in the analysis is "built" using the Preliminary Logging Analysis System (PLANS) computer package developed by the USDA, Forest Service, Seattle, Washington (Twito and McGaughey, 1984).

Step 2. The PROSIM program is loaded into memory.

Step 3. The date, a job title, and the name of the DTM are entered as requested.

Step 4. The DTM file is loaded into memory by PROSIM.

Step 5. The DTM is located on the digitizing (or graphics) tablet by "marking" the bottom corners of the DTM.

Step 6. The location of the landing is marked using the digitizer.

Step 7. The location of the first tailspar is marked using the digitizer.

Step 8. The boundary of the harvest unit is marked using the digitizer.

Step 9. PROSIM calculates the area to be harvested within the boundary.

Step 10. Logging system parameters, such as processing location, yarder type and log size distribution, are entered by the user.

Step 11. The new tailspar is located on the harvest unit boundary by the program.

Step 12. A check is made to see if the whole setting (harvest unit) has been logged. If there is still wood to be yarded PROSIM carries on to Step 13. If the setting is completed it goes to Step 19.

Step 13. The external yarding distance (EYD) is calculated for the new tailspar location.

Step 14. If the EYD is less than 30 metres the program returns to Step 11. and locates the next new tailspar. It is assumed that when the EYD is less than 30 metres the timber has already been removed during road and landing construction.

Step 15. If the EYD is 30 metres or greater the current skyline road number is updated.

Step 16. PROSIM then takes a new profile from the landing to the new tailspar using the DTM data.

Step 17. Cable and yarder mechanics are then used to determine the payload zones along the current skyline road.

Step 18. Logs are assigned from the log size distribution to the skyline road. Loads are then constructed and yarded to the landing. Cycle statistics are recorded and accumulated. When the skyline road has been completed the program returns to Step 11.

Step 19. When the setting has been completed the yarding statistics are summarised.

Step 20. Stump-to-milldoor costs are then calculated for the completed setting. Some additional input is required by the user at this stage.

Step 21. The results of the simulation are then output to the printer and the program terminated.

5.6 COST CALCULATIONS

The COSTS subroutine handles the calculation of unit costs for each phase of the operation from stump to milldoor. A total cost per cubic metre is the final output of the COSTS subroutine. The subroutine, itself, is made up of eight small subroutines (Figure 5-9).

Labour costs have been slowly rising in New Zealand for decades. In mid-1984 New Zealand "floated" its currency on the international money markets. As a result the capital cost of machinery imported from overseas has been very erratic. Most harvesting equipment used in New Zealand is imported from the Northern Hemisphere. The costs used in this thesis, therefore, relate to a specific time period. The time period chosen was the first quarter of 1985. All costs are, of course, in New Zealand dollars (NZ$1 = US$0.5).

5.6.1 Felling costs

The FELLING COSTS subroutine is depicted in Figure 5-10. The program prompts the user for the following stand and setting details:

- mean diameter breast height, DBH (centimetres),
- merchantable stocking, STEMS (tree stems per hectare),

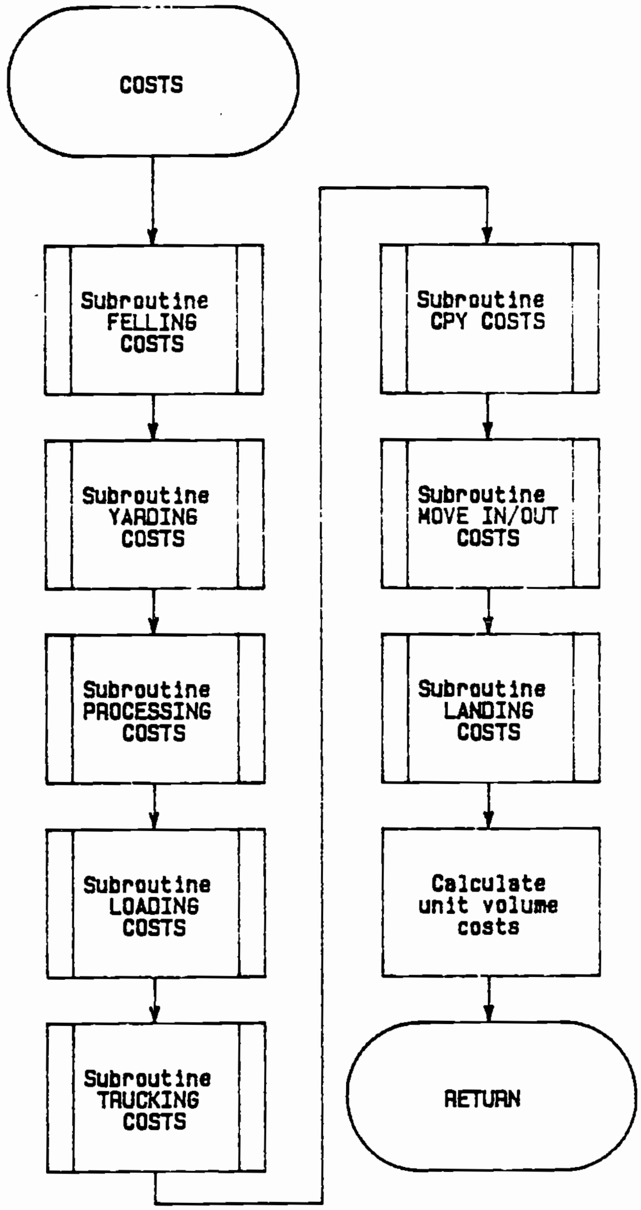

Figure 5-9 Flowchart of cost calculation subroutine.

- undergrowth (PUNGAS [tree ferns] per hectare),
- mean tree volume, TVOL (cubic metres), and
- average slope for the setting, SLOPE (degrees).

The program then calculates the total time to fell all trees on the setting. The felling equations were taken from unpublished work element time standards developed and tested over the past couple of decades by the New Zealand Forest Service Work Study Units. Two equations were used; one where log manufacturing (or partial manufacturing) was carried out at the stump, and one where log manufacturing was carried out on the landing. With minor transformations, the equations, as shown below, were rewritten to reflect felling time (minutes) on a per hectare basis.

Felling with manufacturing at the stump:

```
Felling time =1.32*(STEMS*(0.046*DBH + 0.01*SLOPE + 2.292
             -0.00084*STEMS - 0.00084*PUNGAS + 2.967*TVOL
             -0.345*TVOL^2) + PUNGAS*(0.68 + 0.01*SLOPE))
```

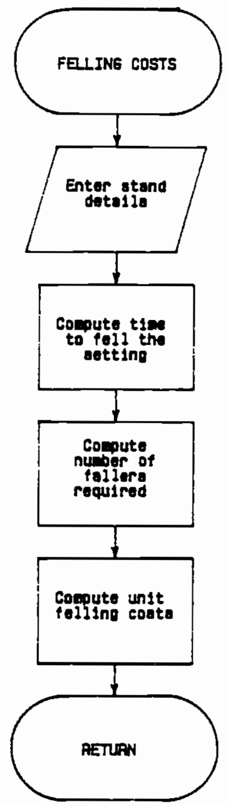

Figure 5-10 Flowchart of felling costs subroutine.

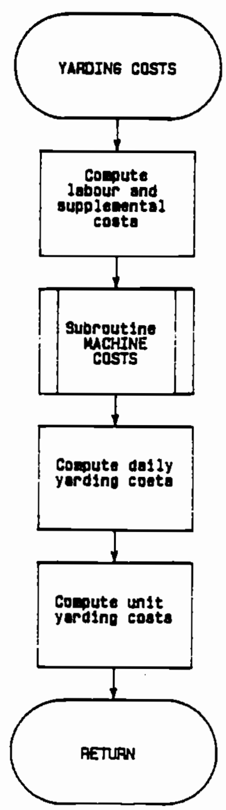

Figure 5-11 Flowchart of yarding costs subroutine.

Felling with manufacturing at the landing:

Felling time =1.32*(STEMS*(0.045*DBH + 0.01*SLOPE + 0.139
- 0.00082*STEMS - 0.00082*PUNGAS)
+ PUNGAS*(0.68 + 0.01*SLOPE))

Total time to fell the setting was computed as the product of the setting area and the felling time per hectare. The number of fallers required to fell the setting was calculated by dividing the total felling time by the number of days it would take the yarder to harvest the setting. Falling should then be balanced with the yarding operation.

All labour in the PROSIM model was charged out at $100 per man-day. Additionally each faller was equipped with a saw and supplies which cost $23 per day to operate. Unit felling cost was computed as:

Unit felling cost = Number of fallers *(Labour cost + Saw cost)/ Setting volume

5.6.2 Yarding costs

The procedure for costing the yarding phase of the harvesting operation is depicted in Figure 5-11. It is an amalgam of costs obtained from the 1984 New Zealand Forest Service Capital Update and a procedure developed by Walker (1976) of the New Zealand Forest Research Institute.

The labour component of the yarding phase was calculated to be $400 per day; one hundred dollars each for two choker setters (breaker outs), one yarder operator, and one crew boss.

Supplemental costs of $45 per day for crew transport, $56 per day for crew accessories, and $60 per day for equipment accessories were included.

In calculating the daily yarder costs it was assumed that the resale value for yarders in New Zealand would be about 10% of the capital cost and that the economic life would be about 10 years. A capital cost of $820,000 for the Madill 071 was taken from the NZ Forest Service Capital Cost Update. Capital costs were not readily available for the Madill 009 and the Washington 88. Costs for these two machines were obtained by indexing costs in the USDA Willamette Appraisal guide. Capital costs of $1,100,000 and $1,085,000 were obtained for the Madill 009 and Washington 88 respectively.

The MACHINE___COSTS subroutine computed daily yarding machine costs (Figure 5-12). Total daily yarding costs were computed as the sum of labour costs, supplemental costs, and yarding machine costs. Unit yarding costs on a per cubic metre basis were computed as the product of total daily costs, the number of days to harvest the setting, and the inverse of total volume harvested from the setting.

5.6.3 Processing costs

This cost refers to processing (or log manufacturing) on the landing (Figure 5-13). Most cable logging operations in New Zealand have three people working on the landing. They unhook pieces when they arrive at the landing, cut them up into logs, assist with skyline road changes and may assist with hooking on logs if the need arises. If logs are not processed on the landing fewer people are required. PROSIM assumes that 3 people are required if logs are processed on the landing, and 1 person if logs are processed at the stump or at a central processing yard. Additionally each man is provided with a chainsaw.

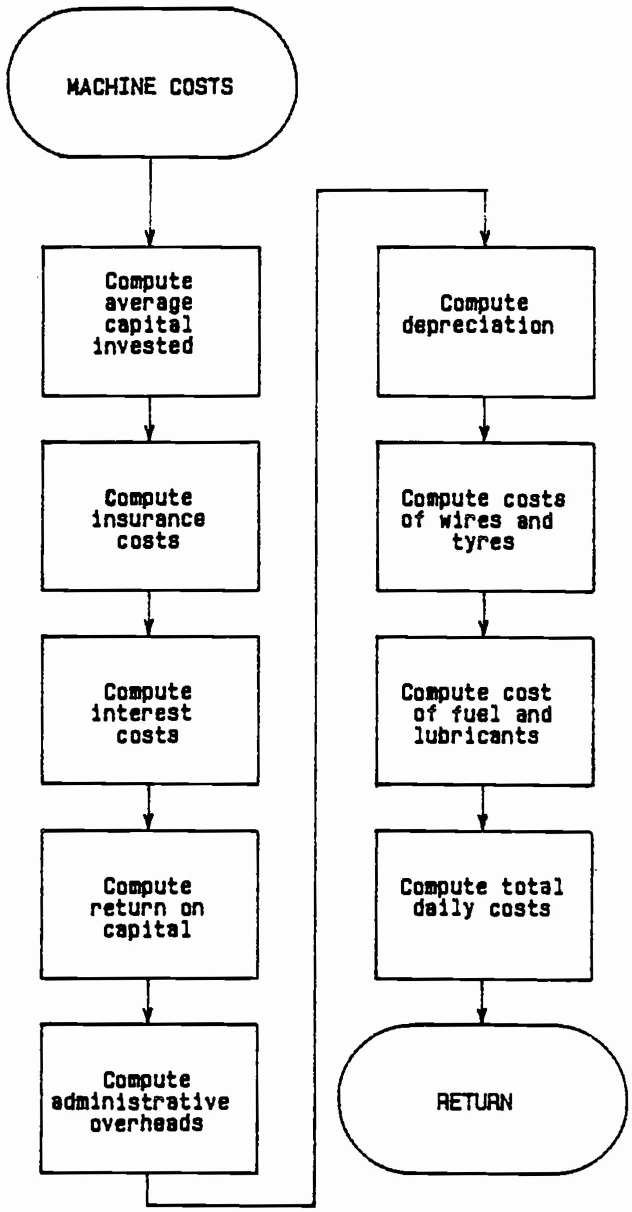

Figure 5-12 Flowchart of subroutine to calculate daily machine costs.

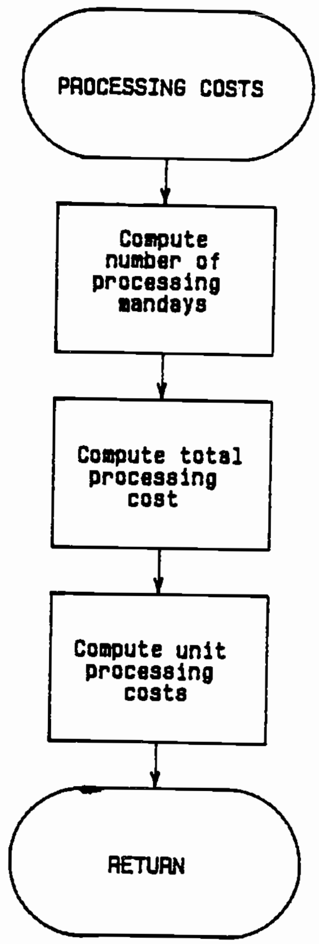

Figure 5-13 Flowchart of processing costs subroutine.

5.6.4 Loading costs

Rubber-tyred front end loaders are usually used with tree length cable logging operations in New Zealand. They require large areas on which to operate. They are particularly effective when many log sorts have to be handled.

When landing space is limited, or log sorts few, hydraulic boom loaders have proven to be more effective than rubber-tyred loaders. There is a move for rubber-tyred loaders to be replaced by hydraulic boom loaders on steeper terrain in New Zealand (Prebble, pers. comm.).

The assumption is made in the PROSIM model that the loading phase of the operation is capable of handling all the wood that the yarder can produce; the loader is not a "bottleneck" to the overall sysem. It is also assumed that, if the loader has excess capacity, it does not load out logs for nearby yarding operations, or assist in yarding wood from along the road edges. Based on the operations the author has viewed in New Zealand, these assumptions appear to be realistic.

Labour costs are set at $100 per day for a single operator.

Loaders generally have a higher resale value than yarders so the resale value was set at 20% of capital cost.

A 91-120 kW size machine with a capital cost of $218,000 and an economic life of 5 years was used in the analysis for the rubber-tyred front end loader. The model only uses a rubber-tyred loader when pieces are extracted tree-length and manufactured on the large landing.

A medium size machine with a capital cost of $434,000 and an economic life of 7 years was used in the analysis for the hydraulic boom loader. The model used the hydraulic boom loader when logs were manufactured at the stump and extracted to a small landing, or were cut into truck lengths at the stump and manufactured into the final log types at a central processing yard.

The daily machine costs for the loaders were computed in the MACHINE__COSTS subroutine. Unit loading costs were computed in a similar manner to unit yarding costs.

5.6.5 Trucking costs

Trucking costs in the PROSIM model are based on research by Stulen (1985). A cost equation was developed

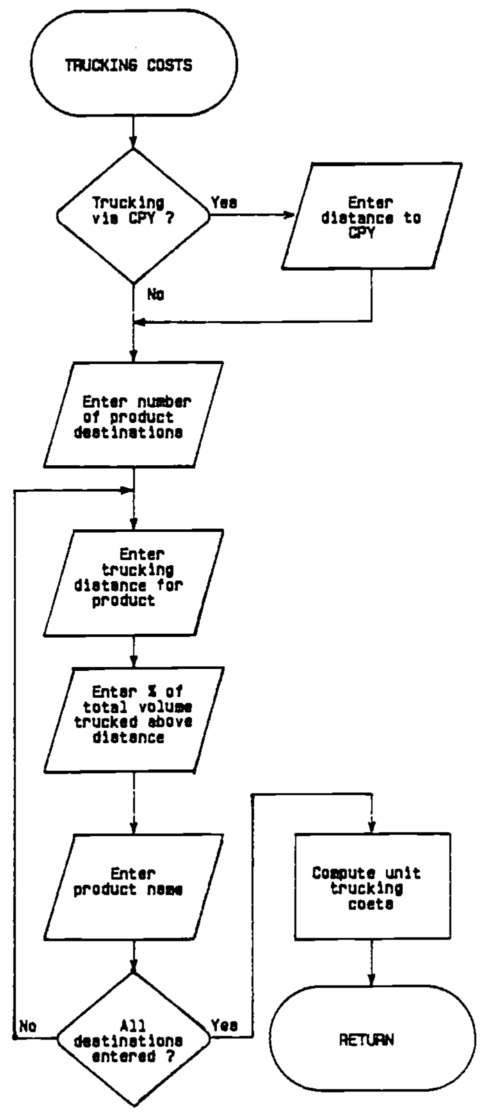

Figure 5-14 Flowchart of trucking costs subroutine.

with one-way haul distance being the independent variable in the equation. Stulen's work was based on trucking on the relatively flat Central Plateau area of the North Island. The cost equation was modified by a 10% upward adjustment to reflect trucking costs for more difficult conditions in other parts of New Zealand. The cost equation used was as follows:

Unit trucking cost ($/cu.m.) = 1.70 + 0.1234*DISTANCE

where DISTANCE is the one-way haul distance in kilometres.

The PROSIM model allows the user to specify truck haul distances for up to 15 products (Figure 5-14). Product names and percentage volume trucked as that product type also need to be specified.

5.6.6 Central processing yard costs

The New Zealand forest industry has very little experience with operating central processing yards. Bryan and others (1976a & b) operated a central processing yard on a trial basis for the Beech Logging Unit in the South Island. Because of the small scale of the operation costs were considered to be excessive.

Central sortyards are well utilised in the Pacific Northwest of America. Compared with New Zealand they have received much more managerial and research attention. Sinclair and Wellburn (1984), in particular, have published detailed reports on the design, economic analysis, and construction of central sortyards in British Columbia. Although, less log manufacturing is carried out in sortyards than in central processing yards, Sinclair's publication was used as a basis for costing a central processing yard operation for New Zealand.

A cost of $7.25 per cubic metre, for a central processing yard, was used in the PROSIM model. Assumptions and details used to arrive at this value are summarised in Appendix C.

5.6.7 Move-in/Move-out costs

Blundell and Cossens (1985) reported times for moving equipment into, and out of, yarding settings. It depended primarily on moving distance and whether the equipment had to be broken down into smaller components for carrying on lowboys. The PROSIM model assumes that all moves are over relatively short distances within a single forest and that equipment does not have to be broken down into small components. The assumption is made that each shift requires about 6 hours (or 0.75 scheduled days). The move-in/move-out costs are, therefore, the cost for all labour (felling, processing, yarding, and loading), supplemental and chainsaw costs, and yarding and loading machine costs for a period of 0.75 days.

5.6.8 Landing construction costs

Twaddle (1984c) has found that landing size for tree length logging operations around New Zealand is dependent, among other things on terrain and soil types. For steep terrain with difficult soil types landings of approximately 0.24 hectare are commonly constructed. A cost of construction for such landings of $15,000 was used in the PROSIM model. The whole landing was assumed to be rocked. The cost is comparatively high for many landings in New Zealand but may be low for landings requiring construction on steep side slopes, with end-hauling of cut-material and extensive rocking. New Zealand has little experience with constructing large landings on steep-side slopes. More research is recommended in this area.

The PROSIM model assumes that small landings will cost about one-sixth of landings used for tree-length extraction, that is, about $2500. Small landings were assumed to be all that was required for log-length extraction where trees were cut to final log lengths at the stump or to truck lengths for hauling to a central processing yard.

Unit landing costs were computed by dividing landing construction cost by the volume extracted from the setting.

5.7 MODEL VERIFICATION AND VALIDATION

Model verification and validation are two important steps in constructing an acceptable simulation model (Pritsker, 1986). Verification involves testing to see that the model behaves as the experimenter intended (Shannon, 1975). Validation involves proving the model to be "true" (Naylor and Finger, 1967).

The verification process was carried out continually through the model's development. Verification can include both quantitative and qualitative analysis. The PROSIM model is made up of many subroutines. Checks were made to verify that individual subroutines were working correctly and that the subroutines were correctly linked together. Individual subroutines were verified either by hand calculation or by comparing the output values with other models. For example, the LOGGERPC skyline payload analysis program, developed by Oregon State University, was used to verify that payloads for individual terrain points were calculated correctly for given line tensions and yarding parameters. Qualitative checks included verifying that output correctly reflected input values. For example, PROSIM prints out a few sentences on the type of logging system analysed, including loader and yarder type. Checks were made to ensure that this was being reported correctly.

A simulation model of a complex, real-world system is always only an approximation to the actual system, regardless of how much effort is put into developing the model. Thus, one should not speak of the absolute validity or invalidity of a model, but rather of the degree to which the model agrees with the system (Law and Kelton, 1982). Validating a model implies that the model developer has some set of criteria for differentiating between those models which are "true" and those models which are "not true" (Naylor and Finger, 1967). Given the difficulty involved with specifying a set of criteria, validation can be reduced to assessing the degree of agreement between the model's predictions and the real world (Shannon, 1975). Even assessing the degree of agreement between the real world and the model is not easy for harvesting cost simulation models. The physical and production parameters on which unit costs are based may be perfectly predicted by the model. However, since there are probably as many different costing systems in existence as there are logging operations, it is unlikely that unit costs predicted by a model would be in complete agreement with the real world. For example, differences in such cost factors as interest rates, depreciation schedules, assumed economic life and local labour rates could cause significant disagreement between model costs and real-world costs. Gibson and others (1983) have stated that " in the case of [a harvesting] cost model, which is prescriptive in nature, the consistency of the results is more important than the accuracy of the results. The model should be capable of gross cost prediction but quantification of the relative costs for alternative systems is most important".

Validation of the PROSIM model was an ongoing process throughout the models development. The following things were done to ensure the greatest possible degree of validity:

- common sense was used throughout the models formulation,
- applicable literature was reviewed and existing theory and useable techniques incorporated where possible,
- subroutines from similar relevant models were sought out and used to avoid "reinventing the wheel",
- an appropriate level of detail was incorporated into each of the model's subroutines to check that values being calculated appeared realistic,
- the model was checked to see that it was performing as expected, e.g. when the number of chokers were decreased it expected, and found, that the mean number of logs hooked would also decrease,
- sensitivity analysis was performed to see how some of the assumptions in the model caused variation in the model output.

The final step in the validation procedure was to compare output with real world systems. Although it was not possible to compare total unit costs for a real-world stump-to-milldoor harvesting system with output from the PROSIM model it was possible to check some of the intermediate outputs of the model, particularly from the trucking and yarding phases of the operation. For example, personal communications with Sheldon Drummond, a logging officer from the New Zealand Forestry Corporation, indicate that the model is predicting trucking costs reasonably accurately.

The yarding phase of PROSIM virtually "drives" the rest of the model. Validation of this portion of the model received the most attention. Long term productivity records for the Madill 009 tree-length operation used as the basis for the yarding equations in PROSIM show daily production varied between 200 and 230 cubic metres (Murphy, 1983b). The output from four areas analysed with the PROSIM model varied between 206 and 228 cubic metres for tree-length operations. The maximum number of pieces extracted during studies of the Madill 009 was 7. PROSIM predicted a maximum number of 6.

Less information is available for validating the models ability to predict productivity and costs for systems with a Madill 071 as the yarder. Long term records of the Madill 071 operation studied, and used as the basis for the equations in PROSIM, show that the system averages about 34 cycles per day. The average predicted by PROSIM for four areas analysed was about 31 cycles, about 5-10% too low. Discussions with Drummond, indicate that productivity levels predicted by PROSIM may be a little low. This is undoubtedly due to the high percentage of delay time used in the model for this machine. Volume per cycle is an important variable in determining harvesting productivity. The average volume per cycle extracted in field trials for the Madill 071 was about one-third of the maximum volume; the same value for this parameter can be computed from the PROSIM output.

No production records or studies were available from New Zealand for validating the output of PROSIM for the Washington 88. The output, however, appears reasonable when compared with, and relative to, the output of the other two yarders.

5.8 ANALYSIS PROCEDURE AND RESULTS

5.8.1 Generation of log distribution coefficients

Six log size distributions were generated using data from the value recovery studies and a program called WEIBULL. WEIBULL, which was written for use on IBM-PC compatible computers (Torres-Rojo, 1987), fits a three-parameter weibull function to log size data using eight different algorithms. The WEIBULL program also gives Chi-square and Kolmogorov-Smirnoff goodness of fit statistics for the distributions. The user selects the distribution which best fits the data. Table 5-1 summarises the log size distribution parameters chosen for the six log bucking patterns. All of the fitted distributions reported in the table were not significantly different from the raw data when tested at a p-level of 0.05 for either the Chi-square or Kolmogorov-Smirnoff statistics.

Table 5-1 3-Parameter Weibull Piece Size Distributions

Bucking Patterns	Pieces per hectare	Coefficients a	b	c
Avis optimal	797	0.010000	0.820000	1.622429
Solly	664	0.000000	0.997478	1.422732
Solly, Dick, Jim	666	0.027017	1.002445	1.647058
Tree-length	200	0.048877	3.425119	2.153411
Fixed 12.6	498	0.000000	1.343852	1.336873
Butt 12.6	395	0.000000	1.713371	1.983210

For each log bucking pattern the number of pieces per hectare to be extracted was also calculated and is shown in Table 5-1.

5.8.2 Inputs to the PROSIM model

The inputs required to run the PROSIM model are described in Appendix B. They could be categorised into three groups; logging system inputs, stand detail inputs, and trucking detail inputs. The first category varied depending on the simulation that was being run. Values for the second category remained constant (except for average slope which was dependent on the harvest unit being simulated) and are shown below:

- DBH = 55 cm.,
- Stocking = 200 stems per hectare,
- Undergrowth = 300 pungas [tree ferns] per hectare,
- Tree volume = 3.1 cubic metres.

Although, the user can specify up to 15 trucking destinations in the PROSIM model, for ease of analysis the simplifying assumption was made that all wood went to the same final destination. In some cases logs are trucked over 240 kilometres to specialty mills in New Zealand. For other mills the average one-way truck haul distance is about 30 kilometres (Myers, 1986). A haul distance of 40 kilometres was input to the PROSIM model when the final log manufacturing location being simulated was at the stump or on the landing. When the timber was sent via a central processing yard for final log manufacture it was assumed that the central processing yard would not always be on the direct route to the mill. Five kilometres extra travel was added to the one-way haul distance to give a total of 45 kilometres.

5.8.3 Simulation runs

When the PROSIM model was first being tested it was noted that for the "same" inputs to the model different outputs could and often did occur. This occurs for three reasons:

(1) The digital terrain model, harvest unit boundary, and landing location are entered each time the simulation model is run using the digitizing tablet. Unless the user is very careful it is difficult to exactly duplicate the inputs, especially for the harvest unit boundary. For example, when locating harvest unit boundaries on a 1:4,000 scale map a one millimetre deviation will result in an error of about 4 metres distance.

(2) The user specifies the location of the first tailspar, and as a result of the algorithm used in the model, the eventual location of all the tailspar locations for the

harvest unit. The landing and tailspar locations determine the terrain profiles, payload capability, and productivity of the yarding system. Productivity and costs, therefore, depend on where the user locates the first tailspar.

(3) As stated in section 5.5, PROSIM is part stochastic/part deterministic. The generation and location of logs on the harvest setting is stochastic based. It is unlikely that the same logs will be located in the same location on the harvest setting for any two simulation runs. The same random number stream was used for all simulations to generate possible log locations <u>and</u> log volumes. Since not all locations lay within the wedge of influence of the skyline cable some of the logs generated were not used.

Because of the above three reasons each treatment (yarder/log bucking pattern combination) in each block (harvest unit) was repeatedly run through the simulation model until the calculated mean total cost per cubic metre was within one percent of the expected mean total cost (Freese, 1967). Bounds were placed on the number of simulation runs, however. Each treatment/block combination was simulated a minimum of five times and a maximum of thirty times. In total over 800 simulation runs were carried out to create the data used in the analysis described in section 5.8.4. The location of the first tailspar on the harvest unit boundary was varied for each simulation run.

Summaries of some of the output values reported by PROSIM are presented for individual yarders, bucking patterns and harvest units in tabular form in Appendix D. Table 5-2 only gives the mean total cost per cubic metre, as summarised from the PROSIM output.

Table 5-2 Summary of simulated total system costs (NZ$/cubic metre)

Area	Yarder	Bucking Pattern AVIS	Solly	S,D&J	Tree	Fixed	Butt
USA1	Madill 009	38.16	35.72	34.94	29.67	42.30	41.28
	Madill 071	41.46	38.78	38.24	32.28	45.25	44.13
	Washington	28.21	26.40	26.13	25.05	34.06	34.96
USA2	Madill 009	40.89	37.77	37.21	30.71	43.55	42.20
	Madill 071	44.25	41.30	40.69	34.28	47.08	46.24
	Washington	30.69	28.75	28.73	29.01	36.34	35.54
NZ1	Madill 009	39.33	36.55	36.25	30.84	43.05	41.88
	Madill 071	52.76	49.35	48.92	39.75	55.17	53.57
	Washington	34.87	32.64	32.32	30.35	39.40	37.94
NZ2	Madill 009	39.71	36.77	36.42	33.88	43.16	42.18
	Madill 071	53.09	50.72	50.91	44.02	56.63	55.77
	Washington	37.71	35.27	35.14	43.32	43.57	42.03

Note: Values shown in **bold** print had more than 10% of the volume left behind on the setting.

Some of the values shown are in bold print. These are for treatments where PROSIM left more than 10% of the setting volume at the stump because of limited payload capability. In the worst instance over 50% of the volume was left at the stump. The large Madill 009 had few problems recovering the volume from the four harvest units. Both the medium sized yarders with small towers and lines had limited payload capability on some of the harvest units. The smaller machines may not have been suitable for some of the units to be logged. The PROSIM model is based on skyline yarding systems where one end of the logs are suspended above the ground. In areas where very little lift is available loggers often use a highlead yarding system (Figure 5-15) where logs are dragged in complete contact with the ground. Yarding cycle times are usually slower under such situations. A quick review of the literature indicated that there appears to be no readily available adjustment factor for converting skyline to highlead costs for the same yarder. An assumption was therefore made that inhaul times would double under highlead conditions and delay times increase by an average of one minute per cycle. These assumptions resulted in cost adjustment factors of between 25 and 45% for the yarding phase. Although yarding costs and loading costs would increase, because of the greater time required to harvest an area, some costs, such as landing construction costs, would decrease because of the costs being spread over a greater volume. For all values in the above table where more than 10% of the volume was left on the setting

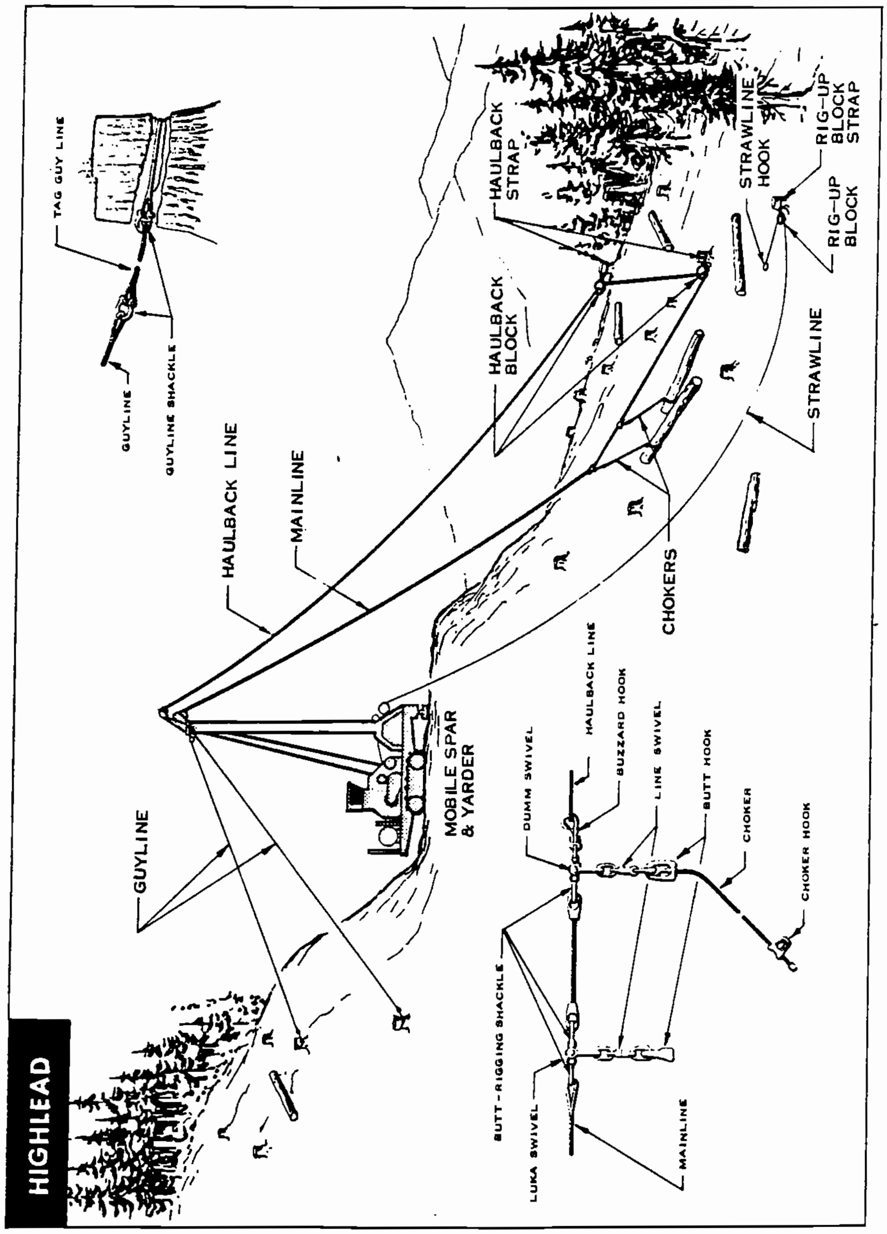

Figure 5-15 Highlead yarding system.

by PROSIM, costs were manually adjusted. Table 5-3 presents a summary of the cost data with values adjusted where necessary.

Table 5-3 Summary of adjusted total system costs (NZ$/cubic metre)

Area	Yarder	Bucking Pattern					
		AVIS	Solly	S,D&J	Tree	Fixed	Butt
USA1	Madill 009	38.16	35.72	34.94	29.67	42.30	41.28
	Madill 071	41.46	38.78	38.24	32.28	45.25	44.13
	Washington	28.21	26.40	26.13	25.38	34.06	34.96
USA2	Madill 009	40.89	37.77	37.21	30.71	43.55	42.20
	Madill 071	44.25	41.30	40.69	34.28	47.08	46.24
	Washington	30.69	28.75	28.73	29.38	36.34	35.54
NZ1	Madill 009	39.33	36.55	36.25	30.84	43.05	41.88
	Madill 071	52.76	50.30	48.92	40.52	56.10	54.55
	Washington	34.87	33.15	32.82	30.30	39.97	38.42
NZ2	Madill 009	39.71	36.77	36.42	33.88	43.16	42.18
	Madill 071	53.09	50.72	50.91	44.65	56.63	55.77
	Washington	37.71	35.27	35.14	42.23	44.18	42.40

5.8.4 ANOVA analysis

An analysis of variance (ANOVA) was carried out on the unadjusted cost data presented in Table 5-2 using a spreadsheet program (SYMPHONY, 1984) and a procedure outlined by Peterson (1985). The ANOVA table is shown below.

Table 5-4 Analysis of variance of unadjusted cost data

Source	Degrees of freedom	Sums of squares	Mean Sum of squares	F	Sign. (p)
Block	3	670.898	223.633	30.83	0.001
Yarder	2	1875.964	937.982	129.30	0.001
Bucking pattern	5	947.645	189.529	26.13	0.001
Interaction	10	130.001	13.000	1.79	0.08
Error	51	369.982	7.254		
Total	71	3994.491			

The analysis of variance of the unadjusted cost data indicates that:

- blocking of the data by harvest unit was effective, that is, there were differences in total system costs attributable to the areas being harvested,
- there are significant differences in total system costs between at least one pair of yarders,
- there are significant differences in total system costs between at least one pair of bucking patterns, and
- there appears to be an interaction between yarders and bucking patterns in determining total system costs.

Because of the significant interaction term the data was reanalysed for each type of yarder and a Fishers

Protected Least Significant Difference test carried out to determine which bucking patterns were significantly different from each other. Table 5-5 shows the mean total system costs for the six bucking patterns, by yarder type. For a given yarder, mean costs with the same letter were <u>not</u> significantly different when tested at a p=0.05 level.

Table 5-5 Mean unadjusted total system costs ($/cu. m.)

	Bucking pattern					
Yarder	AVIS	Solly	S,D&J	Tree	Fixed	Butt
Madill 009	39.52 a	36.70 b	36.21 b	31.28 c	43.02 d	41.89 e
Madill 071	47.89 a	45.04 b	44.69 b	37.58 c	51.03 d	49.93 e
Washington	32.87 a	30.77 a	30.58 a	31.96 a	38.34 b	37.62 b

The ANOVA analysis and Fishers Protected Least Significant Difference test were repeated for the adjusted cost data to see if any differences occurred in the conclusions that would be drawn from the analysis. Table 5-6 shows the ANOVA table for the adjusted cost data.

The analysis again indicated that blocking was effective, there were significant differences between

Table 5-6 Analysis of variance of adjusted cost data

Source	Degrees of freedom	Sums of squares	Mean Sum of squares	F	Sign. (p)
Block	3	689.112	229.704	31.49	0.001
Yarder	2	1906.090	953.046	130.65	0.001
Bucking pattern	5	965.673	193.135	26.48	0.001
Interaction	10	117.767	11.777	1.61	0.15
Error	51	372.023	7.295		
Total	71	4050.664			

yarders, and there were significant differences between bucking patterns. The interaction term was less significant than was found for the unadjusted data. However, least significant difference tests were still carried out on the adjusted cost data grouped by individual yarder. If there is really no interaction and we say there is the consequences are not as bad as saying there is no interaction when there really is. The mean adjusted total system costs are shown in Table 5-7. For a given yarder, mean costs with the same letter were <u>not</u> significantly different when tested at a p=0.05 level.

The results of the ANOVA and LSD analyses were the same for both the adjusted and unadjusted cost data. For the two Madill yarders it was found that the only bucking

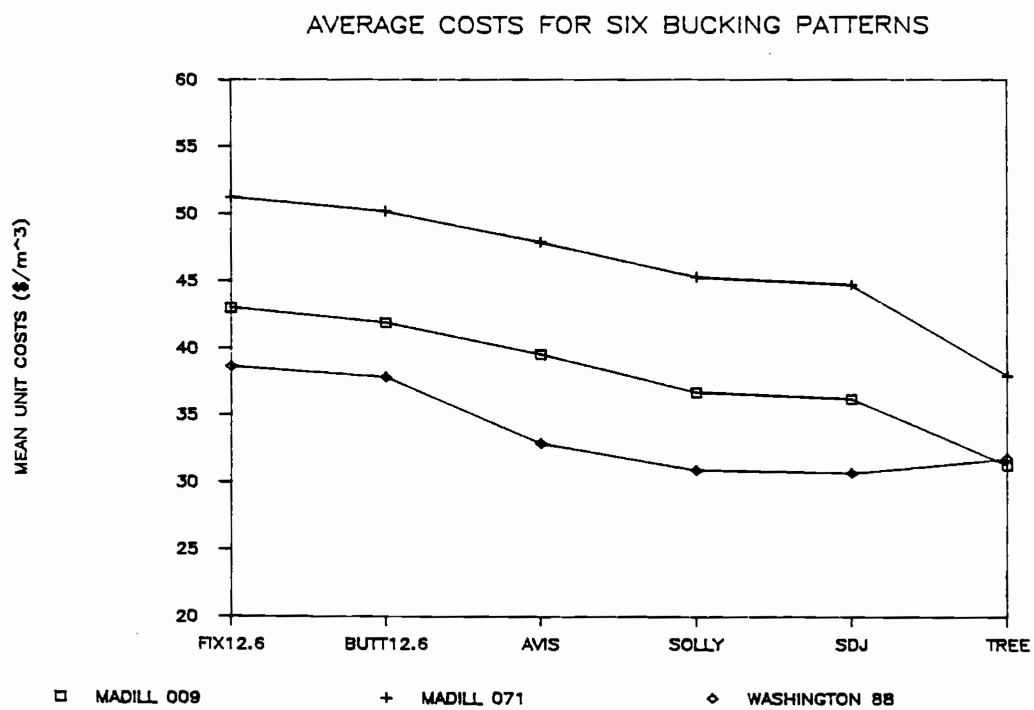

Figure 5-16 Adjusted total system costs for six bucking patterns.

patterns which were not significantly different from each other were the "Solly" bucking pattern and the "Solly, Dick, and Jim" bucking pattern. Since Solly influenced both bucking patterns this is understandable. The data from the Washington yarder could be put into two groups; final manufacture of logs at a central processing yard and final manufacture in the forest, either at the stump or at the landing. Figure 5-16 depicts the adjusted total system costs for the six bucking patterns. It can be seen that costs were highest for the Fixed 12.6 metre length bucking pattern and lowest for the Tree-length bucking pattern.

Table 5-7 Mean adjusted total system costs ($/cu. m.)

	Bucking pattern					
Yarder	AVIS	Solly	S,D&J	Tree	Fixed	Butt
Madill 009	39.52	36.70	36.21	31.28	43.02	41.89
	a	b	b	c	d	e
Madill 071	47.89	45.28	44.69	37.93	51.27	50.17
	a	b	b	c	d	e
Washington	32.87	30.89	30.71	31.82	38.64	37.83
	a	a	a	a	b	b

5.8.5 Distribution of costs

An indication of the relative importance, in cost terms, of the components of the stump-to-mill door harvesting system can be gained by looking at the distribution of costs. Table 5-8 displays the distribution of costs for three of the six bucking patterns for the three yarders. The bucking patterns selected represent each of the three final log manufacturing locations, the stump, the landing and a central processing yard. It can be seen in all cases that yarding is the major cost component of the total system cost, accounting for from 32 to 51% of costs. Trucking and loading are other high cost components. Unlike the Pacific Northwest of the United States of America falling is a minor cost component for steep country harvesting operations in New Zealand. Fifteen to twenty percent of total system costs are accounted for in the central processing yard if final log manufacturing is carried out at this location.

Table 5-8 Distribution of costs (%) and total cost ($)

Harvesting system	Fall	Yard	Process	Load	Activity centre Truck	CPY	Move	Land. Const	Tot. cost
	%	%	%	%	%	%	%	%	$
SOLLY									
Madill 009	3.7	51.7	2.0	21.1	17.6	0	2.3	1.6	36.70
Madill 071	3.4	48.9	2.5	25.6	16.1	0	1.8	1.5	45.28
Wash. 88	4.6	46.2	1.8	19.1	23.1	0	3.0	2.1	30.89
TREELENGTH									
Madill 009	1.4	45.4	5.3	12.6	21.6	0	2.5	11.1	31.28
Madill 071	1.3	44.2	6.7	15.6	19.4	0	2.0	10.6	37.93
Wash. 88	1.5	44.3	5.2	12.4	22.6	0	2.6	11.3	31.82
FIXED 12.6									
Madill 009	3.1	39.0	1.5	16.0	20.6	16.6	1.9	1.3	43.02
Madill 071	2.9	36.0	1.9	20.0	19.0	15.4	1.5	2.9	51.27
Wash. 88	3.6	32.7	1.3	13.5	24.6	20.0	2.4	1.6	38.64

5.8.6 Sensitivity analysis

Looking at the distribution of costs can give a feeling of the relative importance of various harvesting system components. Sensitivity analysis of some of the assumptions used in the simulation model can give a better appreciation. Ten variables were selected for sensitivity analysis:

- felling cost
- yarder capital cost
- factor of safety of cables
- number of chokers available
- log-to-ground angle
- loader capital cost
- trucking cost
- central processing yard (sort) cost
- landing construction cost
- labour costs

A base case condition has to be chosen around which sensitivity can be measured. The base case used in this analysis was the Madill 009 yarder extracting fixed 12.6 metre log lengths to a small landing on the USA1 setting. The fixed length logs would then be trucked to the mill via a central processing yard. Each of the variables were tested individually with a plus and a minus 20% increase

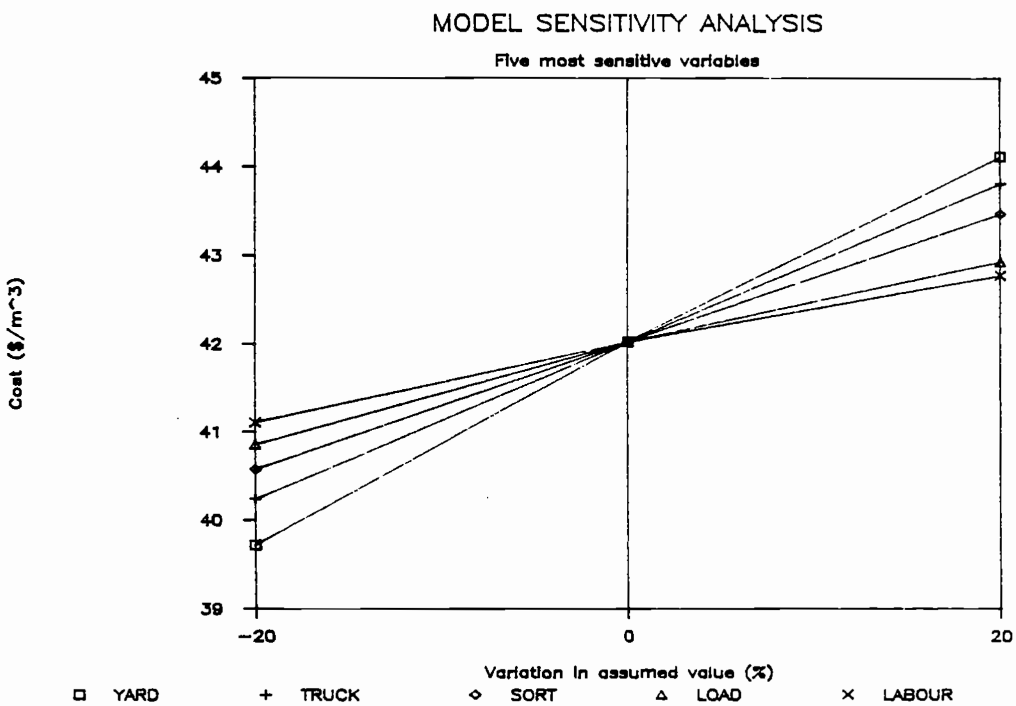

Figure 5-17 Model sensitivity for the five most sensitive variables.

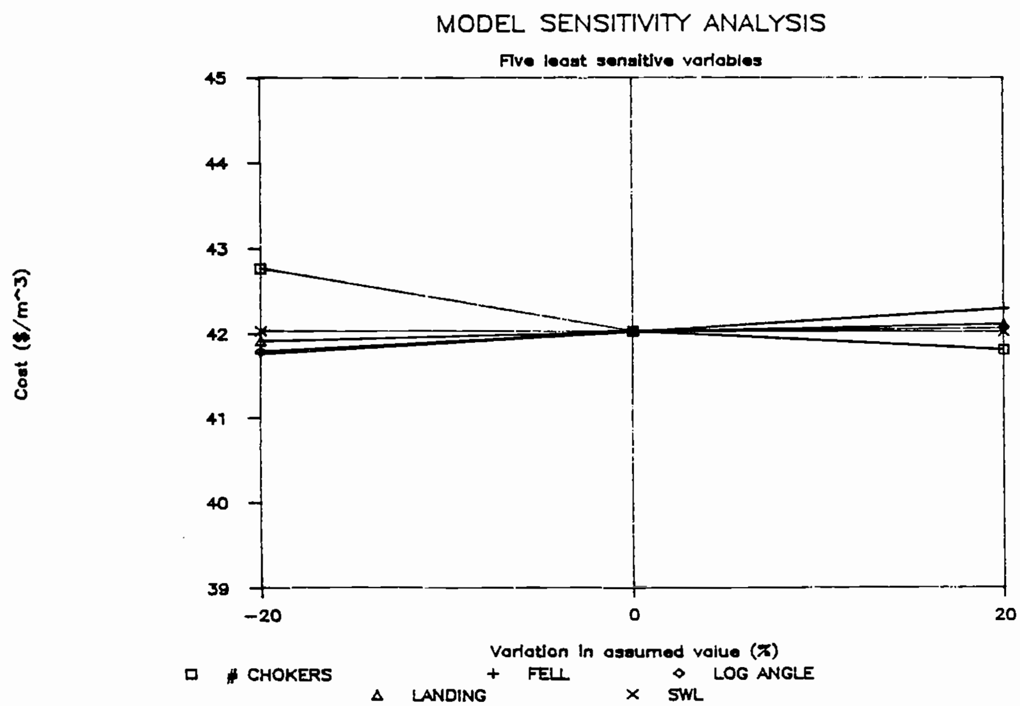

Figure 5-18 Model sensitivity for the five least sensitive variables.

in assumed value. Since the number of chokers could only be varied in integer units the variation was not exactly 20% in that case.

Figures 5-17 and 5-18 show the sensitivity in cost found for the ten variables. The five most sensitive variables in decreasing order of importance were yarder capital cost, trucking cost, central processing yard cost, loader capital cost, and labour cost. The five least sensitive variables were the number of chokers available, the log-to-ground angle, the landing construction cost, the felling cost, and the safety factor for the cables (yarder was torque limited). The importance of these results will be touched on in section 5.9.

5.8.7 Yarding productivity

The yarding phase was the biggest cost component of the total system costs. It was also one of the more sensitive components to changes in assumptions relating to it. For many logging managers the yarding machine productivity is a key indicator of the cost effectiveness of an harvesting operation. Figure 5-19 depicts the average daily productivity for the four harvest unit areas predicted by PROSIM. The bucking patterns listed on the bottom axis of the figure are in order of decreasing piece

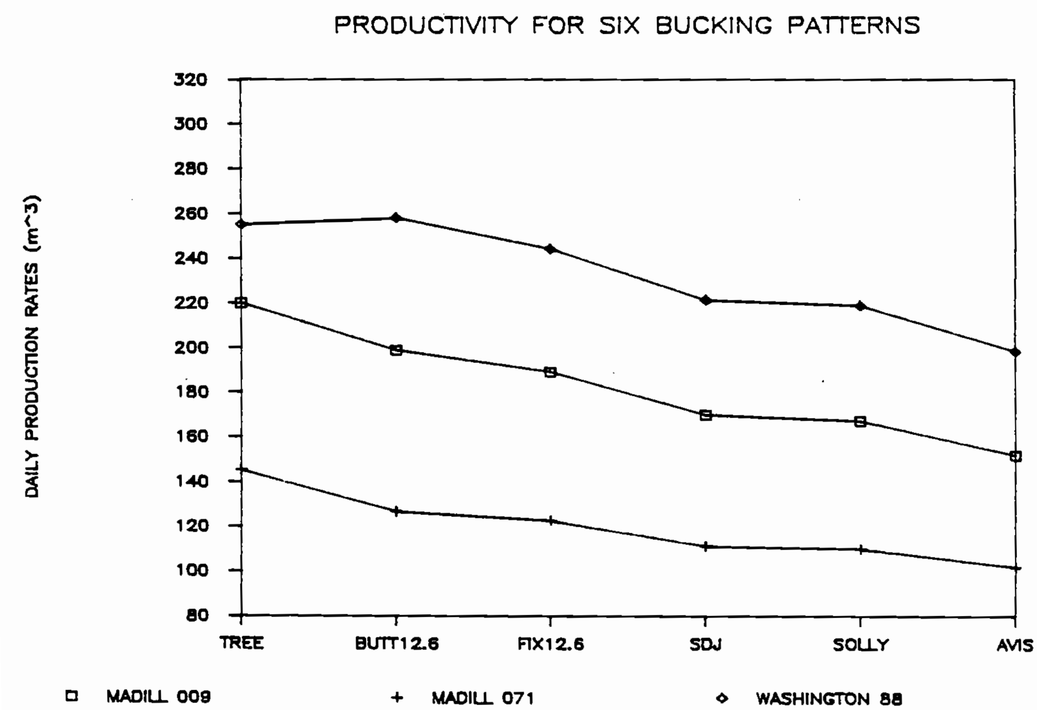

Figure 5-19 Average daily productivity for six bucking patterns.

size from left to right. The strong influence of piece size on productivity can be noted from this figure. Piece size has been noted by many authors as being a key variable of logging machine productivity (Lisland, 1975, Terlesk, 1980, Conway, 1982).

Greatest productivity was found for tree-length extraction to a large landing. Bucking a 12.6 metre butt length from the bottom of each tree and bucking trees into fixed 12.6 metre lengths were the next two most productive alternatives. The least productive alternative was to cut trees into their optimal final log lengths at the stump; the optimal decision being based only on value recovery and made with the aid of a hand held computer.

It must be pointed out that although tree-length logging was generally the most productive system it was also the system with which the smaller yarders had the greatest recovery problems. On the other hand the smaller yarders had fewer problems with recovering a reasonable amount of the volume on the setting when trees were bucked at the stump. Bucking at the stump patterns were the least productive, however.

5.9 DISCUSSION AND CONCLUSIONS

The discussion and conclusions in this section pertain only to harvesting system costs and yarding productivity. Value recovery and other factors will be drawn into the discussion in Chapter 6.

This study showed that significant differences in stump-to-milldoor harvesting costs can be expected when final log manufacturing is carried out in different locations. The worst system could have costs from 15 to 45% higher than the best system.

5.9.1 Log manufacturing on a large landing

The study indicated that tree-length logging to large landings was generally the best system. This assumes, of course, that it is feasible and environmentally acceptable to build large landings. The average difference in system costs between tree-length extraction and log-length extraction (the next best alternative) ranged from $1.11 to $6.76 per cubic metre for the three different yarders.

Using average differences hides the fact, however, that tree-length systems may sometimes result in higher costs than log-length systems. When harvest units had broken terrain and poor deflection the two smaller yarders had difficulty handling reasonable payloads with the tree-length system. In these cases log-length logging resulted in lower costs. For the worst case, tree-length logging was over $7 per cubic metre more expensive than if a log length system had been used. It was assumed that all skylines were rigged to stumps at the backend of the setting for all simulations in this study. Additionally, no multispan systems using intermediate supports were modelled. Use of intermediate supports and tailspars, where necessary, may have increased the range of conditions over which tree-length logging was the preferred system with the smaller yarders.

5.9.2 Log manufacturing at the stump

Although it was found that final manufacturing of logs at the stump was the next best alternative to tree-length extraction, some differences were found between different bucking patterns used at the stump. The level of significance of the differences was dependent on the type of yarder modelled. There was no significant difference between total system costs resulting from two of three bucking patterns modelled for final log manufacturing at the stump. These two patterns were drawn from field data gathered for the value recovery study. Both included the log-manufacturer called Solly. The at-stump bucking pattern that generated the highest system costs was the AVIS pattern. It was assumed for this bucking pattern that the faller had a handheld computer with him at the stump which suggested the optimal way to buck the stem to get the most value out of it. By following the AVIS bucking pattern the average piece size extracted would be considerably smaller than was found for the other two at-stump patterns (0.752 versus 0.908 and 0.924 cubic metres per piece). The large effect that piece size has on yarding productivity and costs has been discussed elsewhere.

5.9.3 Final log manufacturing at central processing yards

Partial processing of logs at the stump, with final log manufacturing at a central processing yard, appeared to be the most costly of the three log manufacturing locations. On average system costs were about $10 per cubic metre higher than for tree-length logging and processing on a large landing. Bucking only a 12.6 metre length from the butt would reduce the difference in system costs by about $1 per cubic metre. Sensitivity analysis of total system costs indicated that the central processing yard cost was one of the more important variables.

Central processing yard costs were assumed to be $7.25 per cubic metre in the analyses. For 10 out of 12 comparisons (3 yarder types on each of 4 harvest units) the central processing yard option would not be viable on a cost competitive basis even if wood could pass through the yard for free ! The other two comparisons required reductions in central processing yard costs in the order of 25% and 95%. The former is possible, the latter unlikely.

5.9.4 Use of smaller yarders

One of the reasons claimed for final manufacturing of logs at the stump rather than on a large landing is that with smaller pieces it would be possible to use a smaller, less expensive yarder. Indications from the simulations are that this may in fact be correct. Log-length yarding with a Washington 88 might be able to produce wood for the same system cost as tree-length yarding with the large Madill 009. The sensitivity analysis highlighted the importance of the capital cost that was assumed for the yarder. When making between-machine comparisons, it is important that capital costs be as accurate as possible. The reader will remember that some of the capital costs were obtained by indexing known costs with overseas costs. As mentioned earlier in this chapter, the data base for the Washington 88 yarder was also extremely weak. Further production time studies on this type of machine will be required before such comparisons can be confidently made.

5.9.5 Landing construction costs

The high cost of constructing large landings, particularly in difficult terrain, is sometimes given as a reason for adopting alternative logging systems. Landing construction costs, on average, accounted for less than 12% of total system costs; this was despite using a large value of $15,000 per landing in tree-length simulations. If large landings can be constructed for less than this value the attractiveness of the tree-length system would increase further. The relative importance of landing construction costs is dependent among other things on the amount of volume serviced by that landing; as harvest unit size decreases proportional landing construction costs increase. Based on the four areas analysed in this study landing construction costs would generally have to rise to at least $20,000, and in some cases over $50,000, before landing costs became a decisive factor in system selection. Further research needs to be carried out to quantify landing construction costs under a range of conditions on steep terrain in New Zealand.

5.9.6 Trucking costs

The only variable determining trucking costs in the PROSIM model was the distance the logs had to be trucked to the central processing yard and mill. All logs trucked were less than 14m in length. Trucking costs used in the model, when simulating final log manufacturing at a central processing yard, could be slightly high. Reduced loading and unloading time, due to the handling of fewer but larger pieces, should reduce truck turn-around time and costs per cubic metre. Additionally, if the central processing yard (CPY) could be sited in a location that would allow hauling of off-highway loads trucking costs may be reduced even further. Since savings could only be made on the landing-to-CPY portion of the total landing-to-mill haul distance the significance of the savings would depend on the relative distance to the CPY. In this study, the CPY was assumed to be one third of the way to the mill. On this basis, even if the assumed costs for the landing-to-CPY portion are 50% too high, trucking costs could only be overpredicted by about $1 per cubic metre. Such an error would not shift the option of final manufacturing at a central processing yard from the least preferred to the most preferred, or even the second preferred option when preference is based soley on total system costs.

5.9.7 Yarding productivity

Many of the steep country areas in New Zealand will see a gradual build-up in the volume to be harvested. It is important that there be some attempt to match harvesting system capability with needs. This may not be easy to do when volumes to be harvested initially are small and the availablity of a range of yarder types is limited. Under such situations yarder productivity becomes very important and may outweigh cost considerations. Tree-length logging to a large landing, the least total system cost alternative, was generally also the most productive yarding system. Bucking a 12.6 metre butt log from the bottom of each tree, or bucking trees into fixed 12.6 metre lengths, were the next most productive systems. If productivity was the main concern these would be preferred to the systems which incorporated the final log manufacturing at the stump.

5.9.8 Conclusions

The main conclusions that I would draw from this study are as listed below:

(1) If it is possible to build large landings and use large yarders we should continue to do so. This conclusion assumes decisions are to be based on total system costs.

(2) If the terrain, soil conditions, or other environmental considerations preclude the use of large landings then our next best alternative, based on total system costs, may be to carry out our final log manufacture at the stump and yard to small landings or roadside.

(3) Smaller yarders with fast line-speeds may be the most viable machine-type if small landings have to be used.

(4) Landing construction costs, although not insignificant, should have little effect on system decisions.

(5) The systems simulation approach, using models such as PROSIM, is a quick and inexpensive method to evaluate many system alternatives. Potentially poor systems can be quickly eliminated from consideration and good systems highlighted.

5.10 RECOMMENDATIONS FOR FUTURE RESEARCH

One of the great things about constructing a harvesting systems simulation model is that the modeler soon realises how little information is available. He begins to wonder what would happen if I had a better data base, if I had made different assumptions, if I had looked at other machinery, and if I had used other costs. These types of questions form the basis for my recommendations for future research. They are not listed in any particular order.

(1) Production studies on the Washington 88 and Madill 071 yarders were limited. This should be remedied as soon as possible. The studies should be designed to reflect a wide range of terrain, stand conditions, and operating conditions.

(2) In the analysis used in this study it was assumed that ground-leading would result in yarding costs which were 25% to 45% greater than if one-end suspension could be used. It is unknown how good that assumption might be. Field measurements should be carried out to compare cycle times and delay times for yarding logs with one-end suspension versus ground leading when little lift is available.

(3) In the model it was assumed that the loader had infinite capacity and would not limit the yarding operation. It was also assumed that the loader operation would work the same hours as the yarder operation. It is recommended that field observations be carried out to determine the limits under which these assumptions might be valid.

(4) The turn-building logic used in PROSIM is one of the key components to the model. Closer field observation of this component may help to strengthen the model. The influence of such features as number of chokers available, hooking more than one log in each choker when possible, and linking chokers to reach distant logs should be investigated.

(5) The safe working load of the cables or the available torque from the yarder determine the payload capability in PROSIM and the turn-building logic determines the load size. By using the cycle-time equations used in PROSIM the implicit assumption is made that the torque/tension/line-speed/load size conditions being modelled are the same as those under which the data for the cycle time equations were gathered. The relationship between torque, tension, and line-speeds requires further attention if it is to be

correctly understood and modelled. The influence of the yarder operator should also be incorporated into the model.

(6) The use of multispan systems and rigged tailtrees was not investigated in this study. These alternatives should be investigated as soon as possible.

(7) Although it has been stated in section 5.9 that landing construction costs should not greatly influence the selection of harvesting systems a better understanding of the magnitude of these costs for a range of conditions would strengthen this conclusion. It is recommended that the work begun by Twaddle (1984) on the factors affecting landing size in New Zealand should be continued and linked to construction costs.

(8) The PROSIM model only simulates extraction from an irregular fan-shaped setting to a large, or small, central landing. It is common practice in the Pacific Northwest to extract log-lengths with smaller yarders to a roadside from parallel, rectangular settings. Such an alternative also needs to be investigated.

(9) As has been stated before, New Zealand has very little experience with operating central processing yards. Some regions within New Zealand are already considering the use of these types of facilities, however. It is important that costs be gathered on these type of enterprises as soon as possible. Indicative operating costs could possibly be obtained by looking at the costs of operating processing yards attached to large integrated forest product plants in New Zealand.

(10) The breakage and loss of logs during yarder extraction needs to be included in the PROSIM model to strengthen the model's validity. More research will have to be done, particularly on log-length extraction systems, to get a better understanding of this occurrence before it could be modelled though.

(11) It was assumed in the PROSIM model that trees and logs were distributed randomly over a setting. This assumption effects the log location and turn-building logic in the model. Data collected from the field should be tested to see if, indeed, a random distribution fits the data best.

(12) All of the analyses carried out in this study were based on a stand of approximately 3.1 cubic metres mean tree volume and 200 stems per hectare stocking. Some of the steep terrain radiata pine plantations to be harvested in New Zealand in the next decade will have higher stockings (up to maybe 400 stems per hectare) and smaller tree sizes (down to maybe 1 cubic metre per hectare). This study should be expanded to include a wider range of stand conditions.

CHAPTER 6. OVERALL ECONOMIC ANALYSIS AND CONCLUSIONS

To compare alternative log manufacturing locations on an even basis both costs and value recovery must be included in a single analytical procedure. This chapter covers stand-level and forest-level economic analyses of alternative manufacturing locations. Results from the previous three chapters were used as the basis for the analyses.

6.1 HARVESTING SYSTEMS CONSIDERED

In the previous three chapters many combinations of log manufacturing locations, bucking patterns, and yarding machines were considered. In this chapter a restricted number of systems will be examined.

First, only one yarding machine will be considered - the Madill 009 rigged as a grabinski skyline. This yarding machine was selected because

(1) its cost and productivity trends lay between and followed those of the other two yarders described in Chapter 5, and

(2) I had much greater "faith" in the data base and time study regression equations used to predict

productivity and costs (since I had collected the data and developed the regression equations myself).

Five bucking patterns at three log manufacturing locations were used in the analysis. These were:

1. STUMP-AVIS - stems were manufactured into the final log types at the stump and yarded to a small landing. A value audit system, such as AVIS, on a hand-held computer was used to assist in optimal log-bucking decisionmaking. Threadgill and Twaddle (1987) have reported that experimental trials with the AVIS system on the Husky Hunter hand-held computer look very promising. It was assumed that if computer aided tools were available the log manufacturers would be able to achieve 99 percent value recovery. A one percent value loss was assumed because of likely inaccuracies in length measurement at the stump.

2. STUMP-S,D,J - stems were manufactured into the final log lengths at the stump <u>without</u> computer-aided assistance. It was assumed that Solly, Dick, and Jim were representative of a cross-section of New Zealand log manufacturers.

3. LANDING-3% LOSS - stems were yarded tree-length to a large landing where they were then manufactured into their final log types <u>without</u> computer-aided assistance (see footnote). It was assumed that the level of value recovered by Solly and Dick at the landing was representative of a cross-section of log manufacturers. Twaddle (1984) has estimated landing size on difficult terrain to be about 0.25 hectares. If each landing services about 8 hectares, and is not rehabilitated and replanted after harvesting, about <u>3%</u> of the steep country land base would be taken out of production. This system assumed a 3% loss in volume and value from each hectare of land harvested. (Note: 0% loss in volume and value was assumed for the stump and CPY options since most of the volume would be extracted to roadside. Additionally it was assumed that the amount of area taken up by roads would be the same for each of the alternatives examined.)

The collection of data for input to a hand-held computer may take five minutes or more per stem. Because of the relatively short cycle times of cable yarding systems it was considered that this would result in high levels of yarding interference if it was done on a landing.

4. LANDING-5% LOSS - this is the same system as above but a 5% loss in the productive land base is assumed. This is equivalent to assuming that each landing (0.24 ha) only services about 5 hectares of forest.

5. CPY - stems are cut into fixed 12.6 metre lengths, yarded to small landings, where they are loaded onto trucks and hauled to a central processing yard. Final log manufacture is carried out at the CPY before hauling to the final mill destinations.

6.2 STAND-LEVEL ANALYSIS

It was assumed for the purposes of this analysis that the stand to be harvested was similar to the one described and studied in Chapter 3 - stocking was about 200 stems per hectare and the total live volume after felling was about 620 cubic metres per hectare. The stand had been pruned and thinned and was cut into the product types described in Chapter 3.

A gross profit equation could be written as:

$$\text{Profit (per ha)} = \frac{(\text{Value-Costs})(\text{Volume})(100\text{-\% area loss})}{100}$$

From the gross profit would have to be subtracted establishment, tending, roading, administrative costs and other overheads. These are not included in this analysis.

The gross profit per hectare can be discounted back to year zero to obtain a net present value. In this analysis a discount interest rate of 12 percent was used (see footnote). The stand described in Chapter 3 was 40 years old at the time of harvest. If silvicultural tending is carried out on time, instead of belatedly as occurred for this stand, it is believed that the same type of stand could be grown in about 30 years. Net present values for both 30 and 40 year rotations are reported below.

Table 6-1 contains the values, costs, yields and gross profit for the five harvesting systems analysed. Table 6-2 also shows net present value figures and percentage differences in profitability.

Banks in New Zealand are currently charging interest rates for loans of about 22 to 25% while the inflation rate is currently about 10 to 13%. This implies a real rate of about 12% should be used for discounting.

Table 6-1 Gross profit calculations

Harvest system	Value $/cu.m.	Costs $/cu.m.	Area loss %	Volume cu.m./ha	Profit $/ha
STUMP-AVIS	52.28	39.52	0	620	7911
STUMP-S,D,J	39.37	36.21	0	620	1959
LANDING-3%	41.90	31.28	3	601	6387
LANDING-5%	41.90	31.28	5	589	6255
CPY	49.51	43.02	0	620	4024

It can be seen from Table 6-2 that the gross profit for the STUMP-AVIS system is close to $1600 per hectare (c. 24%) higher than for the system that would normally be used on steep country in New Zealand, LANDING-3%. If the log manufacturers did not have the assistance of a hand-held computer the gross profit would be considerably lower for the STUMP-S,D,J system than for the LANDING-3% system; $1959 and $6387 per hectare, respectively. The higher costs of extracting smaller pieces must be covered by higher value recovery if processing at the stump is to be a viable alternative.

The last column in Table 6-2 shows the change that would be required in value recovery for there to be no difference between alternatives. No values are given for the STUMP-S,D,J and CPY systems since they do not appear to be major contenders. If value recovery on a landing could be increased by about 5 to 6 percent above that assumed (i.e. to about 83%) there would be no difference between the STUMP-AVIS and LANDING systems - profit would be about $7900 per hectare. Twaddle (1986) has found that tractor logging crews, processing tree-length logs on large landings, currently average about 85% value recovery and with training and incentives should average 90 to 95%. It could be expected that the greater "work pressure" on log manufacturers working on cable-logging landings (due to shorter cycle times) would result in lower value recovery than found for tractor crews. Nevertheless it should not be difficult to raise value recovery on cable logging landings to about 85%. At that stage other considerations come into play in determining which system - processing at the stump or on the landing - is best.

Table 6-2. Stand-level analysis of five harvesting systems

Harvesting system	Profit $/ha	N.P.V. $/ha 30yr	N.P.V. $/ha 40yr	Difference % (*)	Breakeven recovery % (**)
STUMP-AVIS	7911	264	85	+23.9	0
STUMP-S,D,J	1959	65	21	-69.3	NA
LANDING-3%	6387	213	69	0	+5.5
LANDING-5%	6255	209	67	- 2.1	+6.1
CPY	4024	134	43	-37.0	NA

* Change in profit with LANDING-3% as the reference.
** Required change in value recovery for there to be no profit difference between the STUMP-AVIS and LANDING systems (see text on next page).

Alternatively, if value recovery obtained, when stems were processed at the stump with the aid of a hand-held computer, was about 5.3% lower than assumed (i.e., about 94.7%) there would be no difference in gross profit per hectare between the STUMP-AVIS system and the LANDING-3% system - profit would be about $6400 per hectare. It is unlikely that computer-aided value recovery at the stump would be quite that low.

For the CPY alternative to be selected other considerations would need to be taken into account. Central processing yards permit the accumulation and segregation of specialist products that would not be practically feasible to segregate and store in the forest for individual harvest operations. High premiums for such specialist products might reduce the difference in gross profit between this and other alternatives. Further research is needed in this area before this option should be dismissed.

6.3 FOREST-LEVEL ANALYSIS

Land taken out of production by building large landings could be expected to reduce the ability to meet even flow constraints from a forest. A forest-level analysis allows one to attach an opportunity cost to the the reduced ability to meet even-flow constraints. In some countries, such as the United States, the need to have an even-flow of timber volume is particularly important.

The greatly uneven distribution of age classes for the plantation forests of New Zealand, as depicted in Figure 1-2 on page 3 of this thesis, has caused some problems in gradually building up to a sustainable yield. Sharp changes in yield would be difficult for the forest industry to quickly accomodate. New Zealand is currently reducing its minimum harvest age to fill in the gap in available yield caused by the nadir in planting levels in the 1950's. The minimum harvest age is expected to increase again in the mid-1990's (Levack, 1978).

An allowable cut effect (ACE) analysis (Davis and Johnson, 1987) was carried out using a software package called SHRUB, an expanded version of the HARVEST program (Barber, 1983), to determine the effect that alternative log manufacturing systems would have on forest-level economics under gradually varying even flow constraints. It is assumed that the reader has some familiarity with ACE analysis procedures.

A 100 hundred year planning horizon (about three rotations for radiata pine) was assumed with a minimum harvest age of either 25 or 30 years. A gradually varying even flow analysis (sequential in SHRUB terminology) based on a 15 year look ahead period was used.

The following assumptions were made for the analyses:

1. The forest to be analysed was 1000 hectares in area and had the same distribution of age classes as the combined plantations of New Zealand (see Figure 1-2). The entire forest was classed as having steep terrain.

2. The yield tables for the forest are as shown in Table 6-3. and depicted in Figure 6-1. Two other yield tables were also analysed. The results are shown in Appendix E but for clarity of presentation are not presented in this chapter. The conclusions drawn from using the other two yield tables would not change from those presented below.

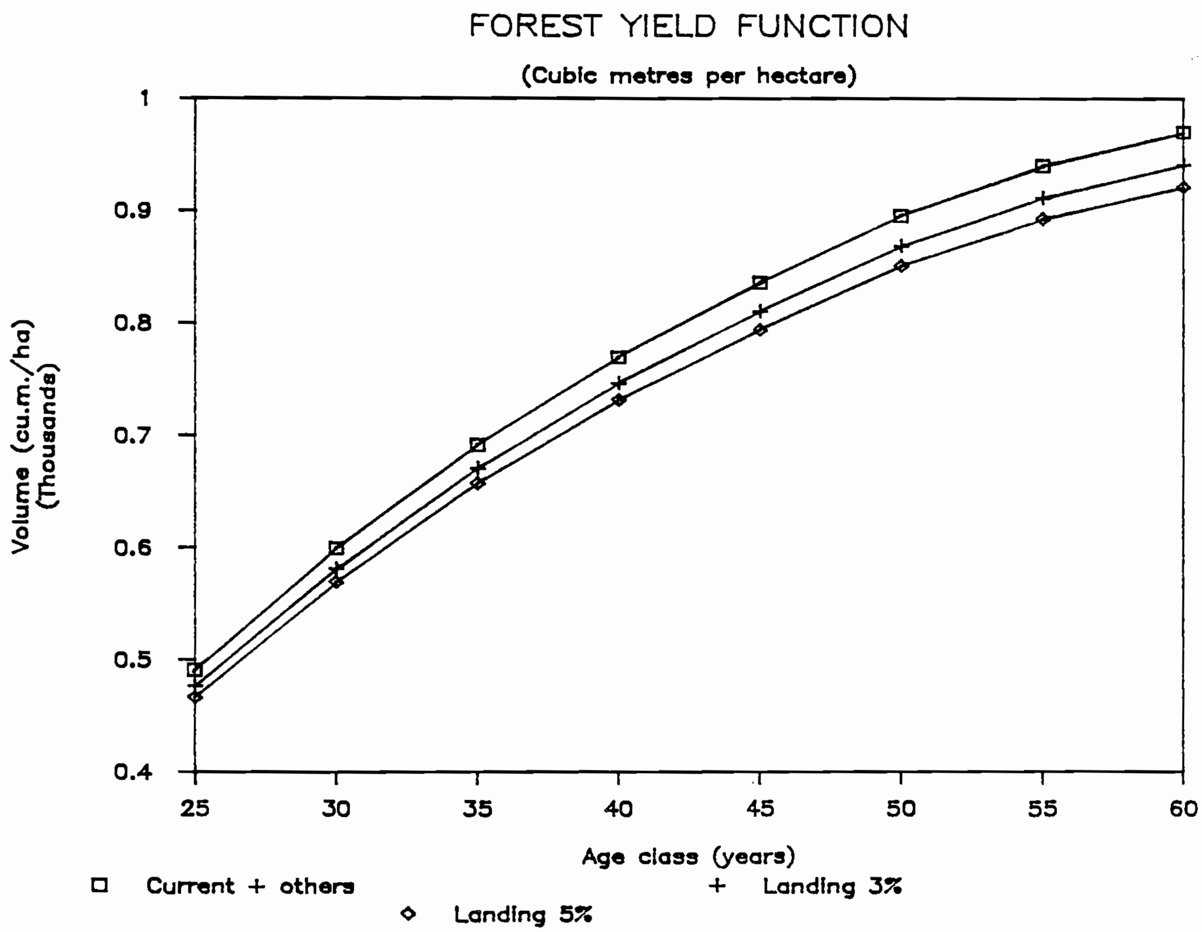

Figure 6-1 Forest yield functions.

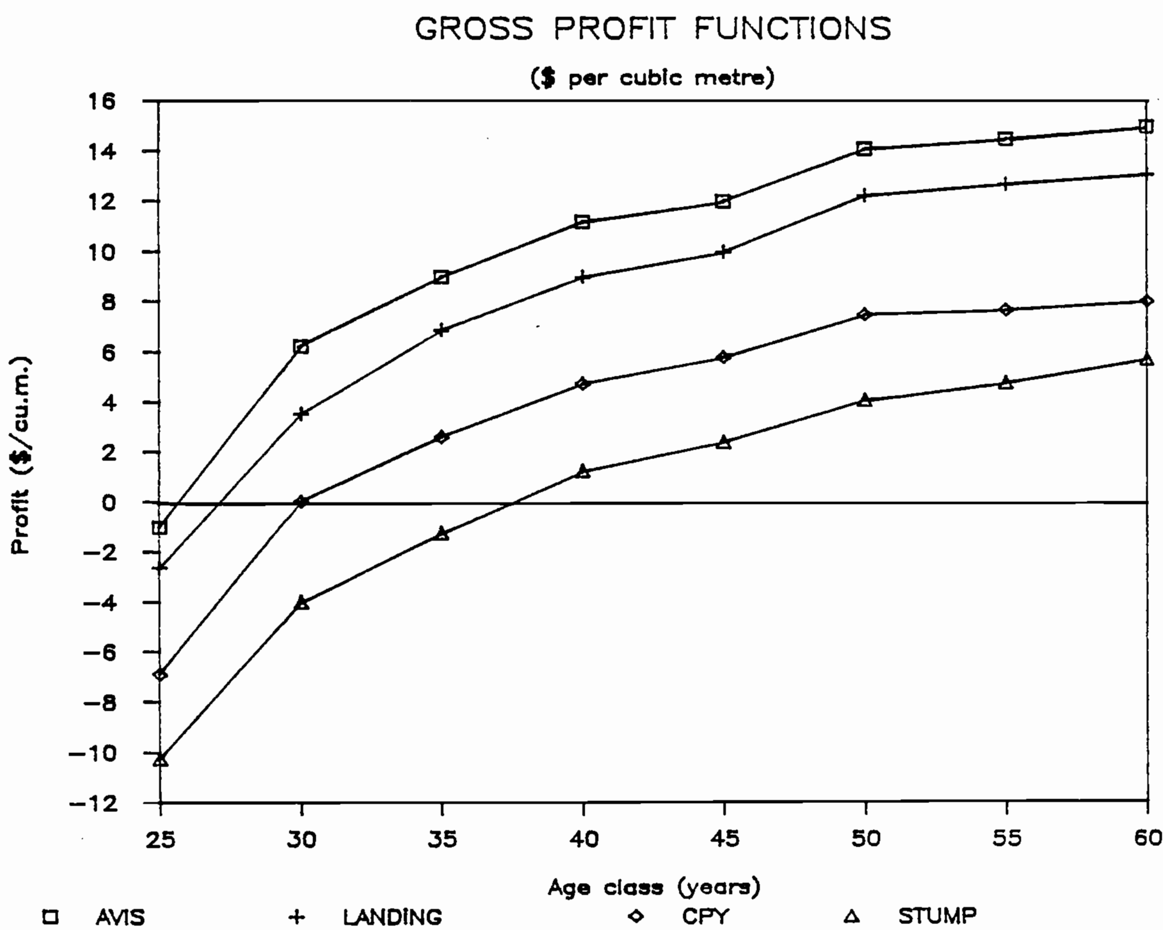

Figure 6-2 Gross profit functions.

3. All stands were assumed to be stocked with 200 stems per hectare.

Table 6-3 Forest yield tables (cubic metres per hectare)

Age class (years)	Current stands	Regenerated stands AVIS	S,D,J	LAND-3%	LAND-5%	CPY
26-30	491	491	491	476	466	491
31-35	600	600	600	582	570	600
36-40	692	692	692	671	657	692
41-45	770	770	770	747	732	770
46-50	836	836	836	811	794	836
51-55	896	896	896	869	851	896
56-60	940	940	940	912	893	940
61-65	970	970	970	941	922	970

4. The gross profit per cubic metre for various aged stands and harvesting systems was as shown graphically in Figure 6-2. The values are shown in greater detail in Appendix E. These values were obtained by extrapolating and indexing values and costs from the studies reported in Chapters 3, 4 and 5. Costs were indexed against a piece-size cost function developed by Terlesk (1980). Geerts and Twaddle (1985) have shown that optimal log value follows an increasing nonlinear volume-based function. Their relationship was used as an index to derive new values for various age classes based on the mean value found for the study reported in Chapter 3. These costs and values can only be classed as broadly indicative and should be treated as such.

Table 6-4 shows a summary of the results of the ACE analyses. It can be seen that the results are similar to those of the stand-level analysis. Log manufacturing at the stump without the aid of a hand-held computer would result in substantially lower net present value than log manufacturing on a large landing. For a minimum harvest age of 25 years the NPV would be negative. If a value audit system on a hand-held computer were available one could expect that there would be a 25 to 30% increase in NPV compared with manufacturing on a landing. The NPV from the CPY system was about half that of manufacturing on a landing and about one third of log manufacturing at the stump with the aid of a handheld computer.

Table 6-4 Summary of allowable cut effect analyses

Harvest system	Minimum harvest age			
	25 years		30 years	
	NPV ($1000)	Diff. (%)*	NPV ($1000)	Diff. (%)*
STUMP-AVIS	1114	+ 30.4	1175	+ 25.5
STUMP-S,D,J	- 103	-112.1	108	- 88.5
LANDING-3%	854	0	936	0
LANDING-5%	854	0#	936	0#
CPY	316	- 63.0	475	- 49.3

* Percentage difference from NPV for the LANDING-3% system.
\# Differences less than 0.1%.

6.4 OVERALL CONCLUSIONS

The overall conclusions that can be drawn from the studies reported in this thesis are as follows:

1. Where possible New Zealand should continue to build large landings and use large yarders. Small improvements in value recovery on the landing make it the most economic alternative.

2. For environmental and physical reasons it may not be possible to build large landings. Final log manufacturing at the stump is a viable alternative if hand-held computers are available to aid in optimal log-bucking decisionmaking. Use of the AVIS system for final log manufacturing at the stump should receive serious consideration and research effort. Research effort is needed to determine the best way to implement AVIS in terms of cost, timing, and training strategies.

3. If hand-held computers are not available final log manufacturing at the stump can be expected to result in higher costs and lower value recovery than the traditional method of tree-length extraction to, and final log manufacturing on, large landings.

4. The central processing yard alternative could not be classed as a preferred option on the basis of these studies.

5. The importance of value recovery in overall economics has been strongly highlighted in this thesis. The differences between people in their ability to obtain high value recovery from a stem should be recognised by management and incorporated into manpower selection, training, and management schemes. The gains that can be obtained, as shown in the extensive work carried out by Twaddle of the New Zealand Forest Research Institute, have been confirmed by results of this thesis.

6. Selection from alternative harvesting systems must be done on an overall economics basis. Basing decisions on productivity, or cost, or value recovery alone may lead to sub-optimal decisions.

6.5 OVERALL RECOMMENDATION FOR FUTURE RESEARCH

My overall recommendation for future research in this area would be that a systems level approach to the research problem should be taken. Concentrating the research effort on costs alone, or value recovery, or land taken out of production could result in the adoption of sub-optimal decisions. An attempt must also be made to quantify environmental, nutritional, and ergonomic factors in economic terms if a true understanding of the costs and benefits of the various log manufacturing alternatives is to be gained. This will undoubtedly require a greater interdisciplinary approach to the problem than I have taken in this thesis.

Since the conclusions drawn from this study were based on a single representative stand and a limited number of log manufacturers and logging systems there is some risk, the magnitude of which is unknown, that the conclusions are wrong for certain conditions. This study should be repeated in a wider range of stands and with more log manufacturers to strengthen the conclusions drawn.

6.6 APPLICATION TO THE USA

This research project was funded by the New Zealand government and was intended to examine alternative harvesting options operating under New Zealand conditions. The study was carried out using New Zealand log values, labour costs, machinery costs, production equations and so on. The results may, therefore, not be applicable to forest harvesting operations in other countries. It is recommended that this study should be <u>repeated</u> for United States conditions before accepting these conclusions as being applicable to the USA.

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APPENDICES

APPENDIX A. HP-9020 BASIC code for the PROSIM model.

```
100  ! ********************************************************
110  ! *************          PROSIM        *******************
120  ! ******** Processing options simulation ***************
130  ! ***********    written by G. Murphy *******************
140  ! ********************************************************
150 Start: PRINTER IS CRT
160         OUTPUT KBD USING "#,B";255,75
170         OPTION BASE 1
180         DEG
190         COM U,V,Xlines,Ylines,Map_s,Sin,Cos,X0,Y0,Digit,Z$,Msus$,INTEGER Print_add,Dig_add
200         COM /Dtm_load/ Hsec,Usec,Hdig,Vdig,Cint,Unit,S3
210         COM /Dtm/ INTEGER G(101,101)
220         DIM Aux_dist(20),Aux_pntr(20),Comb(10),Log_wt(750)
230         DIM Payload(60),Payzone(60),Pdist(15),Perim(2,1000),Prodtype$(15)[15]
240         DIM Prof(2,30),Volper(15),Xin(750),Yin(750),Pointer(750)
250         INTEGER Temp(10)
260         DIM Dtmstore$[40]
270  PRINT "        ********************************************************"
280  PRINT "        *************          PROSIM        ******************* "
290  PRINT "        ******** Processing options simulation ***************"
300  PRINT "        ***********    written by G. Murphy *******************"
310  PRINT "        ********************************************************  "
320  PRINT LIN(2)
330 !
340 !                       *** SYSTEM DEPENDENT PARAMETERS ***
350 !
360         Print_add=401         !Address of hard copy printer
370         Dig_add=406           !Address of digitizer
380         Msus$=":CS80,5"       !Mass storage unit specifier for hard disc
390         Digit=1000            !1000 units per inch with CalComp
400         Hdig=48               !Width of digitizer active surface in inches
410         Vdig=36               !Height of digitizer active surface in inches
420         Dir$="Plans_dtm/"
430 !
440 !
450 !    MASS MEMORY DEVICES ARE IMPLICITLY USED IN:
460 !        LINES Name_that_dtm
470 !        SUBPROGRAM -- Dtmstore
480 !
490 !
500 ! -->  CHECK TO SEE THAT THE PRINTER AND DIGITIZER ARE TURNED ON
510 !
520         CALL Periph_check(Print_add,Dig_add)
530 !
540 ! --> SET DIGITIZER IN RUN MODE
550 !
```

```
560        CALL Set_dig("RUN")
570 !
580 ! --> CHECK TO SEE THAT THE DIGITIZER'S CURSOR IS ON THE ACTIVE AREA
590 !
600        CALL Active_check(Dig_add)
610 !
620 ! --> CREATE THE DIRECTORIES NEEDED BY THE PLANS PACKAGE
630 !
640        CREATE DIR "Plans_dtm"&Msus$;RETURN Error
650 !
660 ! --> INITIALIZE AND CLEAR SYSTEM
670 !
680        MASS STORAGE IS Msus$
690        Turn_wt=Slope=Setting_end_flg=Turns=0
700        Turnvol_ssq=Turnvol_sum=Turnno_ssq=Turnno_sum=0
710        Seednumber=57684
720        No_too_big=Ntb=0
730        Max_vol=Max_no=Max_cycle=0
740        Min_vol=Min_no=Min_cycle=99999
750        Unit=0
760        Z$="Z$Z$Z$Z"
770        Map_s=1
780        Hsec=0
790        MAT G=(0)
800        MAT Log_wt=(0)
810        Vol_too_big=0
820  !
830        FIXED 1
840        RANDOMIZE Seednumber
850        INPUT "Enter the date, e.g. 14_June_1986",Date$
860        INPUT "Enter a job title e.g. USA2_Run1",Rn$
870 !
880 ! --> GET THE DESIRED DTM NAME
890 !
900        INPUT "Enter the data file name for the desired DTM unit.",Z$
910        IF LEN(Z$)>14 THEN 900
920 !
930 ! --> CHECK TO SEE THAT THE INPUT DTM EXISTS ON THE HARD DISC ... IF IT
940 ! --> DOESN'T SET UP THE FILE NAME, MSUS, AND DIRECTORY IN Dtmstore$
950 !
960        CALL Name_that_dtm(Dtmstore$,Dir$,Msus$,Z$)
970 !
980 ! --> READ IN THE DTM HEADER INFORMATION FROM THE REQUESTED DTM
990 !
1000       GOSUB Read_dtm_data
1010 !
1020 ! --> Read_dtm_data CAN RETURN AN ERROR CONDITION IF THE DTM REQUESTED
1030 ! --> IS NOT AVAILABLE ... IN THIS CASE ASK THE USER TO RE-SPECIFY A
1040 ! --> DTM NAME
1050 !
```

```
1060        IF Error THEN 900
1070 !
1080 ! --> ONLY 1 DTM UNIT CAN BE
1090 ! --> LOADED AT A TIME ... THIS IS SIGNALED BY Hsec=0
1100 ! --> READ GRIDDED DTM DATA
1110 !
1120            CALL Getdtm(Xlines,Ylines,G(*),Z$,Dtmstore$)
1130 !
1140 ! --> FILL HOLES IN THE DTM ... THERE SHOULD BE NO HOLES IN THE DTM AS
1150 ! --> THEY WERE FILLED WHEN THE DTM WAS CREATED, BUT THIS PREVENTS
1160 ! --> POSSIBLE ERRORS RESULTING FORM ELEVATIONS OF 0 FEET
1170 !
1180        CALL Fill_holes(Xlines,Ylines,G(*))
1190 !
1200 ! --> GET THE LOWER LEFT AND LOWER RIGHT CORNERS OF THE DTM FOR ALIGNMENT
1210 !
1220        GOSUB Lowerleft
1230        GOSUB Lowerright
1240 !
1250 ! --> CONVERT MAP DIMENSIONAL VARIABLES TO DIGITIZER UNITS
1260 !
1270        U=U*Digit
1280        V=V*Digit
1290        Map_s=Map_s/Digit
1300 !
1310 ! --> RESET MSUS TO HARD DISK
1320 !
1330        Msus$=":CS80,5"
1340 !
1350 !
1360 !
1370      GOSUB Landing
1380      GOSUB First_road
1390      GOSUB Digitize_border
1400      GOSUB Area
1410      GOSUB Logging_sys
1420              PRINT LIN(1)
1430              PRINT "**** YARDING SIMULATION IN PROGRESS ******"
1440              PRINT LIN(1)
1450      Mark=1  ! This is a marker for where the tailspar is on the boundary
1460      GOSUB New_tailspar
1470      GOTO End_setting
1480      GOTO Mineyd_check
1490      GOSUB New_profile
1500      GOSUB Clap2   ! Cable logging analysis program
1510      GOSUB Yarding_sim
1520      GOTO 1460
1530      GOSUB Summary
1540      GOSUB Costs   !
1550      GOSUB Output  ! Reporting section of program
```

```
1560     END
1570 ! ######################################################################
1580 ! ######################################################################
1590 Read_dtm_data:      !
1600 !
1610       Error=0
1620 !
1630 ! --> TRY TO ACCESS THE DTM FILE
1640 !
1650       ASSIGN @A TO Dtmstore$;FORMAT OFF,RETURN Error!open file
1660 !
1670 ! --> IF ACCESS IS IMPOSSIBLE, REQUEST A NEW DTM NAME OR STORAGE DEVICE
1680 !
1690       IF Error THEN
1700          OUTPUT KBD USING "#,B";255,75
1710          PRINT LIN(15);"The DTM file: ";CHR$(129);Dtmstore$;CHR$(128);"
is not available on the specified"
1720          PRINT "storage device.  You must specify a new DTM file name."
1730          BEEP 1000,.5
1740       ELSE
1750 !
1760 ! --> IF ACCESS IS POSSIBLE, READ THE DTM HEADER INFORMATION
1770 !
1780          ENTER @A;Temp(*)  ! READ HEADER
1790          ASSIGN @A TO *    ! CLOSE FILE
1800          Xlines=Temp(1)
1810          Ylines=Temp(2)
1820          Map_s=Temp(3)
1830          U=Temp(4)
1840          V=Temp(5)
1850          Hdig=Temp(6)
1860          Vdig=Temp(7)
1870          Hsec=Temp(8)
1880          S3=Temp(9)
1890          Cint=Temp(10)
1900          U=U/100      ! U & V ARE STORED IN INCHES/100
1910          V=V/100
1920          Hdig=48  !Hdig/100
1930          Vdig=36  !Vdig/100
1940          Vsec=FRACT(Hsec/100)*100  ! Hsec:  HHVV   HH=# HORIZONTAL UNITS
1950          Hsec=INT(Hsec/100)        !              VV=# VERTICAL UNITS
1960          Vspace=U*Map_s/(Xlines-1)
1970          Hspace=V*Map_s/(Ylines-1)
1980          Unit=FRACT(S3/100)*100    ! S3:    S3UU   S3=
1990          S3=INT(S3/100)            !              UU=
2000       END IF
2010       RETURN
2020 !
2030 Lowerleft:!*****************************************************************
2040 !
```

```
2050 !
2060 ! --> GET THE LOWER LEFT CORNER OF THE REQUESTED DTM UNIT
2070 !
2080        GRAPHICS OFF
2090        CALL Set_dig("RUN")
2100        CALL Flush_digit(A$)
2110        DISP "Digitize the LOWER LEFT corner of the DTM unit."
2120        FOR I=1 TO 3
2130           BEEP 5000,.25
2140           WAIT .2
2150        NEXT I
2160        REPEAT
2170           CALL Digit(X0,Y0,S$,Mode$,A$)
2180        UNTIL A$<>"U"
2190        CALL Flush_digit(A$)
2200        BEEP 1750,.075
2210        BEEP 2000,.05
2220        RETURN
2230 Lowerright:!*****************************************************************
2240 !
2250 !
2260 ! --> GET THE LOWER RIGHT CORNER OF THE REQUESTED DTM UNIT
2270 !
2280        DISP "Digitize the LOWER RIGHT corner of the DTM unit."
2290        REPEAT
2300           CALL Digit(X2,Y2,S$,Mode$,A$)
2310        UNTIL A$<>"U"
2320        BEEP 1750,.075
2330        BEEP 2000,.05
2340        CALL Flush_digit(A$)
2350 !
2360 ! --> COMPUTE SIN AND COS OF MAP ROTATION ANGLE
2370 !
2380        Sin=SIN(ATN((Y2-Y0)/(X2-X0)))
2390        Cos=COS(ATN((Y2-Y0)/(X2-X0)))
2400        DISP ""
2410        RETURN
2420 ! -------------------------------------------------------------
2430 Landing: ! Digitize location of landing
2440       PRINT LIN(1);"Digitize the location of the landing using any cursor
button"
2450       REPEAT
2460          CALL Digit(X2,Y2,S$,Mode$,A$)
2470       UNTIL A$<>"U"
2480       BEEP 1750,.075
2490       BEEP 2000,.05
2500       CALL Flush_digit(A$)
2510       Xstart=((X2-X0)*Cos+(Y2-Y0)*Sin)*Map_s
2520       Ystart=((Y2-Y0)*Cos-(X2-X0)*Sin)*Map_s
2530       PRINT "X,Y LANDING",Xstart,Ystart
```

```
2540       RETURN
2550 ! ------------------------------------------------------------------
2560 First_road: !  Digitize the location of the first skyline road tailspar
2570             !  on the setting boundary.
2580       PRINT LIN(1);"Digitize the location of the first tailspar on the se
tting boundary"
2590       REPEAT
2600          CALL Digit(X2,Y2,S$,Mode$,A$)
2610       UNTIL A$<>"U"
2620       BEEP 1750,.075
2630       BEEP 2000,.05
2640       CALL Flush_digit(A$)
2650       Xend=((X2-X0)*Cos+(Y2-Y0)*Sin)*Map_s
2660       Yend=((Y2-Y0)*Cos-(X2-X0)*Sin)*Map_s
2670       Xbeg=Xend
2680       Ybeg=Yend
2690       PRINT "X,Y BEGINNING",Xbeg,Ybeg
2700       Dist=SQR((Xend-Xstart)^2+(Yend-Ystart)^2)
2710       Sky_road_no=0
2720       First_flag=1
2730       RETURN
2740 ! -------------------------------------------------------
2750 Digitize_border:  ! Digitizes setting boundary
2760        Ncount=0
2770        PRINT LIN(1);"Digitize the boundary of the setting in an anti-cloc
kwise direction using any      cursor key."
2780        PRINT "NOTE: You must start digitizing at the first tailspar locat
ion."
2790        CALL Flush_digit(Button$)
2800        IF (Ncount>3) AND (SQR((Xperim-Perim(1,1))^2+(Yperim-Perim(2,1))^2
)<3.0) THEN  GOTO 2980
2810        CALL Digit(X1,Y1,A$,"R",Button$)
2820        Xperim=((X1-X0)*Cos+(Y1-Y0)*Sin)*Map_s
2830        Yperim=((Y1-Y0)*Cos-(X1-X0)*Sin)*Map_s
2840        IF Button$[1,1]<>"U" THEN 2860
2850        GOTO 2800
2860  !
2870        IF Ncount=0 THEN  GOTO 2910
2880        Min_dis_check=SQR((Xperim-Perim(1,Ncount))^2+(Yperim-Perim(2,Ncoun
t))^2)
2890        IF Min_dis_check>1.0 THEN
2900        BEEP 880
2910        Ncount=Ncount+1
2920        Perim(1,Ncount)=Xperim
2930        Perim(2,Ncount)=Yperim
2940        ELSE
2950        GOTO 2800
2960        END IF
2970        GOTO 2800
2980        RETURN
```

```
2990  ! -------------------------------------------------------------
3000 Area:  ! Calculates the area of the setting
3010        ! See BYTE magazine (February 1987) for a description of
3020        ! this algorithm.
3030        Area=0
3040        FOR J=2 TO Ncount
3050          Area=Perim(1,J)*Perim(2,J+1)-Perim(1,J+1)*Perim(2,J)+Area
3060        NEXT J
3070        Area=Perim(1,Ncount)*Perim(2,2)-Perim(1,2)*Perim(2,Ncount)+Area
3080        Area=ABS(Area/20000)
3090        PRINT "AREA = ",Area
3100        Area_got=0
3110        RETURN
3120 ! -------------------------------------------------------------
3130 Logging_sys:  !  Machine and system characteristics
3140     IF First_flag=0 THEN 3640
3150     PRINT LIN(1);"Machine size = Large (0) or Medium (1)"
3160     INPUT Mach_size
3170     PRINT LIN(1);"Log manufacturing location = Stump   (0)"
3180     PRINT "                              Landing (1)"
3190     PRINT "                              CPY     (2)"
3200     INPUT Man_loc
3210     PRINT "Manufacturing location = ",Man_loc
3220     PRINT LIN(1);"Pieces per hectare to be extracted"
3230     INPUT Pieces
3240     PRINT LIN(1);"Coefficents for weibull log distributions (a, b, c) "
3250     INPUT Aa,Bb,Cc
3260     Density=1000     ! Pinus radiata density = 1000kg/cubic metre
3270     IF Mach_size=0 THEN
3280        Hsh=27.0                       ! m
3290        Tsh=1.0                        ! m
3300        Hbw=2.13                       ! kg/m (22mm diam.)
3310        Mlw=4.33                       ! kg/m (32mm diam.)
3320        Hbta=12000                     ! kg
3330        Hbdiam=.022                    ! m
3340        Hbcorelength=0.74              ! m
3350        Hbcorerad=0.255                ! m
3360        Mlta=24000                     ! kg
3370        Carr_wt=250                    ! kg
3380        Rs_time=30                     ! minutes
3390        Rs_dist=13.5                   ! m
3400     ELSE
3410        Hsh=14.0
3420        Tsh=1.0
3430        Carr_wt=200
3440        Hbw=1.08                       ! 16mm diam.
3450        Skyw=2.78                      ! 26mm diam.
3460        Mlw=2.13                       ! 22mm diam.
3470        Hbta=6200
3480        Hbdiam=0.016
```

```
3490       Hbcorelength=0.533
3500       Hbcorerad=0.1775
3510       Mlta=12000
3520       Skyta=15500
3530       Rs_time=75
3540       Rs_dist=15.0
3550    END IF
3560              IF Man_loc=1 THEN
3570                 Loc=1
3580                 Cog=0.35              ! Centre of gravity from big end
3590              ELSE
3600                 Loc=0
3610                 Cog=0.5
3620              END IF
3630       Lat_dist=Rs_dist/2
3640    RETURN
3650 ! -----------------------------------------------------------------
3660 New_tailspar:! Determine co-ordinates of new tailspar location
3670  IF First_flag=1 THEN 4110
3680  ! --------------------------------------------------
3690  Minshift=SQR((Xend-Xbeg)^2+(Yend-Ybeg)^2)
3700  Prop2=0
3710  Y_prime=0
3720  M_equ=(Ystart-Yend)/(Xstart-Xend)
3730  Gamma=ATN(-1.0/M_equ)
3740  Xquad=Xend
3750  Yquad=Yend
3760  GOSUB Quadsec
3770  Y_lat=Yend+Dir*Lat_dist*SIN(Gamma)
3780  X_lat=Xend+Dir*Lat_dist*COS(Gamma)
3790  M_lat=(Y_lat-Ystart)/(X_lat-Xstart)
3800  B_lat=Ystart-M_lat*Xstart
3810  FOR J=Mark+1 TO Ncount
3820  Xquad=X_lat
3830  Yquad=Y_lat
3840  GOSUB Quadsec
3850  Delta=ATN(M_lat)
3860  !
3870  ! Equations below are derived from "Elementary Linear Algebra" pages 109
and 209, H. Anton (1984)
  3880     Trial_tailspar=ABS(-1.0*M_lat*Perim(1,J)+Perim(2,J)-1.0*B_lat)/SQR(M_
lat^2+1)
  3890     Y_prime_last=Y_prime
  3900     Y_prime=-1*(Perim(1,J)-Xstart)*SIN(Delta)+(Perim(2,J)-Ystart)*COS(Del
ta)
  3910     Prop1=Prop2
  3920     Prop2=Trial_tailspar/Lat_dist
  3930     IF (Quad=1) AND (Y_prime<0) THEN 4100
  3940     IF (Quad=2) AND (Y_prime>0) THEN 4100
  3950     IF (Quad=3) AND (Y_prime>0) THEN 4100
```

```
3960     IF (Quad=4) AND (Y_prime<0) THEN 4100
3970  !
3980        IF Trial_tailspar<Lat_dist THEN
3990          GOTO 4100
4000        ELSE
4010  !
4020  !
4030          IF (Y_prime_last>0) AND (Y_prime<0) THEN Prop1=-1*Prop1
4040          Proportion=(1-Prop1)/(Prop2-Prop1)
4050          Xend=Perim(1,J-1)+Proportion*(Perim(1,J)-Perim(1,J-1))
4060          Yend=Perim(2,J-1)+Proportion*(Perim(2,J)-Perim(2,J-1))
4070          Mark=J-1
4080          GOTO 4110
4090        END IF
4100  NEXT J
4110  First_flag=0
4120  IF (J=Ncount+1) AND (Sky_road_no>3) THEN Setting_end_flg=1
4130  RETURN
4140  ! ------------------------------------------------------
4150 Quadsec:  ! Determines which quadrant tailspar is in.
4160  IF Xquad>Xstart THEN
4170     IF Yquad>Ystart THEN
4180       Quad=1
4190       Dir=-1.0
4200     ELSE
4210       Quad=4
4220       Dir=1.0
4230     END IF
4240  ELSE
4250     IF Yquad>Ystart THEN
4260       Quad=2
4270       Dir=-1.0
4280     ELSE
4290       Quad=3
4300       Dir=1.0
4310     END IF
4320  END IF
4330  RETURN
4340  ! ---------------------------------------------------------
4350 End_setting: ! Checks if have completed yarding simulation
4360      IF Setting_end_flg=1 THEN 1530
4370  GOTO 1480    ! Mineyd check
4380  ! ----------------------------------------------------------------
4390 Mineyd_check:  ! Checks to see if external yarding distance is > 30m.
4400  Eydmin=SQR((Xstart-Xend)^2+(Ystart-Yend)^2)
4410  IF Eydmin<30 THEN
4420      GOTO 1460       ! New Tailspar
4430  ELSE
4440      Sky_road_no=Sky_road_no+1
4450  END IF
```

```
4460  GOTO 1490  ! New profile
4470 ! -----------------------------------------------------------------
4480 New profile:  ! Creates a new profile
4490       MAT Prof=(0)
4500       Width_xx=U*Map_s/(Xlines-1)
4510       Width_yy=V*Map_s/(Ylines-1)
4520       Dist=SQR((Xstart-Xend)^2+(Ystart-Yend)^2)
4530       Num_pts=26
4540       Delta_dist=Dist/(Num_pts-1)
4550       Profile_angle=ATN((Yend-Ystart)/(Xend-Xstart))
4560       Delta_x=COS(Profile_angle)*Delta_dist*SGN(Xend-Xstart)
4570       Delta_y=ABS(SIN(Profile_angle)*Delta_dist)*SGN(Yend-Ystart)
4580       X=Xstart
4590       Y=Ystart
4600       FOR J=1 TO Num_pts
4610          Xline=INT(X/Width_xx)+1  !Nearest line # to the left of point
4620          Yline=INT(Y/Width_yy)+1       !Nearest line # below the point
4630          Extra_y=(Y-(Yline-1)*Width_yy)/Width_yy!For interpolating elev
4640          V1=G(Xline,Yline)*(1-Extra_y)+G(Xline,Yline+1)*Extra_y
4650          V2=G(Xline+1,Yline)*(1-Extra_y)+G(Xline+1,Yline+1)*Extra_y
4660          Prof(1,J)=PROUND(Delta_dist*(J-1),0)      !Horiz distance
4670          Prof(2,J)=PROUND(V1+(V2-V1)*(X-(Xline-1)*Width_xx)/Width_xx,0)!E
lev
4680          X=X+Delta_x
4690          Y=Y+Delta_y
4700       NEXT J
4710       RETURN
4720 ! -----------------------------------------------------------------
4730 Clap2:  ! Cable logging analysis program - calculates payloads and
     payload zones.
4740  Landing=1
4750  Tailspar=26
4760  Cw=Carr_wt
4770  Chok_len=5                         !  Chocker length (m)
4780  IF Loc=0 THEN
4790   Loglen=10                         !  Log length (m)
4800   Beta=8.5                          !  Log to ground angle
4810  ELSE
4820   Loglen=25
4830   Beta=3.5
4840  END IF
4850  Mu=.6                              !  Coefficient of friction
4860  Wc=1                               !  Width of carriage (m)
4870  FOR J=Landing+1 TO Tailspar-1
4880    FOR Kchok=1 TO 2
4890      IF Kchok=1 THEN
4900        Chok_len=5
4910      ELSE
4920        Chok_len=1
4930      END IF
```

```
4940  IF Mach_size=0 THEN
4950     W1=W2=W4=Hbw
4960     W3=Mlw
4970     Skyline$="R"                      ! Running skyline
4980     Ta=Hbt=Hbta
4990  ELSE
5000     W1=W2=Skyw
5010     W3=Mlw
5020     W4=Hbw
5030     Ta=Skyta                          ! Slackline
5040     T4=Hbt=Hbta
5050     Skyline$="SL"
5060  END IF
5070  Dl=Prof(1,J)-Prof(1,Landing)
5080  Dr=Prof(1,Tailspar)-Prof(1,J)
5090  Ml_mark=0
5100  Hb_mark=0
5110  GOSUB 6090
5120  Hl=Prof(2,Landing)+Hsh-Prof(2,J)-Cl
5130  Hr_prime=Prof(2,J)+Cl-Prof(2,Tailspar)-Tsh
5140  Hr=ABS(Hr_prime)
5150  IF Hr_prime<0 THEN 5210         ! Check if carriage above the chord
5160  Dr_prime=Hr*(Dr+Dl)/(Hr+Hl)    !
5170  IF Dr_prime>=Dr THEN            !
5180     Wnet=0                       !
5190     GOTO 5830                    !
5200  END IF                          !
5210  GOSUB Torque_check
5220  !***********SKYLINE 1**********
5230  Tu=Ta
5240  D=Dl
5250  H=Hl
5260  W=W1
5270  T_line=0
5280  GOSUB 5910
5290  V1c=Vl
5300  Hh1=Hh
5310  !**********SKYLINE 2**********
5320  D=Dr
5330  H=Hr
5340  W=W2
5350  IF (Prof(2,J)+Cl)>(Prof(2,Tailspar)+Tsh) THEN
5360  Tu=Ta-W*Hl
5370  T_line=W*Hl
5380  GOSUB 5910
5390  V2c=-Vu
5400  V2=Vl
5410  Hh2=Hh
5420  ELSE
5430  Tu=Ta-W*(Hl-Hr)
```

```
5440  T_line=W*(Hl-Hr)
5450  GOSUB 5910
5460  V2c=Vl
5470  V2=Vu
5480  Hh2=Hh
5490  END IF
5500  IF Skyline$="R" THEN 5530
5510  IF Skyline$="SL" THEN 5570
5520  !**********HAULBACK 4**********
5530  ! RUNNING
5540  Hh4=Hh2
5550  V4c=V2c
5560  GOTO 5740
5570  ! SLACKLINE
5580  D=Dr
5590  H=Hr
5600  W=W4
5610  IF (Prof(2,J)+Cl)>(Prof(2,Tailspar)+Tsh) THEN
5620  Tu=T4-(W*Hl)
5630  ELSE
5640  Tu=T4-W*(Hl-Hr)
5650  END IF
5660  IF Tu<W*D/2 THEN Tu=T4=0
5670  GOSUB 5910
5680  Hh4=Hh
5690  IF (Prof(2,J)+Cl)>(Prof(2,Tailspar)+Tsh) THEN
5700  V4c=-Vu
5710  ELSE
5720  V4c=VI
5730  END IF
5740  !**********MAINLINE 3**********
5750  Hh3=(TAN(Alph)*(Hh1-Hh2-Hh4)-(V1c+V2c+V4c-Cw)+(W3*((Dl^2)+(Hl^2))^.5)/2)
/(Hl/Dl-TAN(Alph))
5760  V3c=TAN(Alph)*(Hh1+Hh3-Hh2-Hh4)-V1c-V2c-V4c+Cw
5770  Tmcheck=SGN(Hh3)*SQR(Hh3^2+V3c^2)+Hl*W3
5780  IF Tmcheck>Mlta OR Ml_mark=1 THEN 6180   !  Secant search
5790  Wv=V1c+V2c+V3c+V4c-Cw
5800  Wnet=Wv/(1-((COS(Slope)-SIN(Slope)*TAN(Beta))*(COS(Slope)-Mu*SIN(Slope))
/(2*(1+Mu*TAN(Beta)))))
5810  IF Wnet<0 THEN Wnet=0
5820    IF Kchok=1 THEN
5830      Payload(J)=Wnet
5840    ELSE
5850      Payload(J+30)=Wnet
5860    END IF
5870    NEXT Kchok
5880  NEXT J
5890  GOTO 6810
5900  ! ------------------------------------------------------------------
5910  !***SUBROUTINE FOR HH GIVEN TU,D,H,RIGID LINK***
```

```
5920  L1=(H^2+D^2)^.5
5930  IF Tu>=W*D/2 THEN
5940     Hh=(Tu*D/L1)*(1-(W*D/(2*Tu))^2)^.5-(W*D*H)/(2*L1)
5950     Vu=(Tu^2-Hh^2)^.5
5960     Vl=Vu-W*L1
5970  ELSE
5980     Vu=Vl=0
5990  END IF
6000  RETURN
6010  ! -----------------------------------------------------------------
6020  !***SUBROUTINE FOR VU GIVER HH,D,H,RIGID LINK***
6030  L2=(H^2+D^2)^.5
6040  Vu=(Hh*H/D)+(W*L2/2)
6050  Vl=Vu-W*L2
6060  Tu=(Vu^2+Hh^2)^.5
6070  RETURN
6080  ! -----------------------------------------------------------------
6090  ! Subroutine to calculate carriage height from the ground
6100  Slope=ATN((Prof(2,J)-Prof(2,J+1))/(Prof(1,J+1)-Prof(1,J)))
6110  IF (Slope<0) AND (TAN(Slope)<=-1*Mu) THEN Slope=-1*Slope
6120  Alph=ATN((1/Cog)*TAN(Slope+Beta)+(-1.0+1/Cog)*(COS(Slope)-Mu*SIN(Slope))
/(SIN(Slope)+Mu*COS(Slope)))
6130  IF Alph=90 THEN Alph=89.95
6140  Ltg=SIN(Beta+Slope)*Loglen-(TAN(Slope)*Loglen*COS(Beta+Slope))
6150  Cl=Chok_len*SIN(Alph)+Ltg+Wc
6160  RETURN
6170  ! --------------------------------------------------------------------
6180  ! ---Secant search for new tensions if mainline tension exceeded----
6190  IF Skyline$="R" THEN       ! Madill 009
6200     IF Ml_mark=0 THEN
6210        First_guess=Hbt
6220        Z1=Tmcheck
6230        Second_guess=Ta=Hbt-1000
6240        Ml_mark=1
6250        GOTO 5230
6260     ELSE
6270        Z2=Tmcheck
6280        M=(Z2-Z1)/(Second_guess-First_guess)
6290        First_guess=Second_guess
6300        Z1=Z2
6310        Second_guess=Ta=First_guess-(Z2-Mlta)/M
6320        IF (Ta-T_line)<(W*D/2) THEN
6330          Ta=Second_guess=T_line+W*D/2
6340        END IF
6350        IF ABS(Z2-Mlta)<5 THEN 6780
6360        GOTO 5230
6370     END IF
6380  ELSE                           !  Madill 071
6390     IF Ml_mark=0 THEN
6400        First_guess=Hbt
```

```
6410         Z1=Tmcheck
6420         Second_guess=T4=Hbt-1000
6430         Ml_mark=1
6440         GOTO 5230
6450     ELSE
6460         IF T4<=0 THEN
6470           IF Hb_mark=0 THEN
6480               First_guess=Skyta
6490               Z1=Tmcheck
6500               Second_guess=Ta=Skyta-1000
6510               Hb_mark=1
6520               T4=0
6530               IF ABS(Z2-Mlta)<5 THEN
6540                 GOTO 6780
6550               ELSE
6560                 GOTO 5230
6570               END IF
6580           ELSE
6590               Z2=Tmcheck
6600               M=(Z2-Z1)/(Second_guess-First_guess)
6610               First_guess=Second_guess
6620               Z1=Z2
6630               Second_guess=Ta=First_guess-(Z2-Mlta)/M
6640               IF ABS(Z2-Mlta)<5 THEN 6780
6650               GOTO 5230
6660           END IF
6670         ELSE
6680           Z2=Tmcheck
6690           M=(Z2-Z1)/(Second_guess-First_guess)
6700           First_guess=Second_guess
6710           Z1=Z2
6720           Second_guess=T4=First_guess-(Z2-Mlta)/M
6730           IF ABS(Z2-Mlta)<5 THEN 6780
6740           GOTO 5230
6750         END IF
6760     END IF
6770 END IF
6780 GOTO 5790
6790 STOP
6800 !-------------------------------------------------------------------
6810 !  Subroutine to calculate payload zones
6820 !
6830 FOR Kchok=1 TO 2
6840  IF Kchok=1 THEN
6850      Plus=0
6860  ELSE
6870      Plus=30
6880  END IF
6890 Tpstart=INT(Hsh*25/Eydmin)+1+Plus
6900 Tpfinish=Tailspar-2+Plus
```

```
6910  IF (Tpstart<2+Plus) THEN Tpstart=2+Plus
6920  Zonemin=Payload(Tpstart)
6930  FOR I=(1+Plus) TO (Tpstart-1)
6940     Payzone(I)=Zonemin
6950  NEXT I
6960  !
6970  FOR I=Tpstart TO Tpfinish
6980    IF Payload(I)>Zonemin THEN  GOTO 7000
6990    Zonemin=Payload(I)
7000    Payzone(I)=Zonemin
7010  NEXT I
7020  Payzone(Tpfinish+1)=Payzone(Tpfinish)
7030  NEXT Kchok
7040  IF Payzone(31)<1.0 AND Payzone(1)<1.0 THEN
7050    Sky_road_no=Sky_road_no-1
7060    GOTO 1460
7070  ELSE
7080    GOTO 7100
7090  END IF
7100  RETURN
7110  ! ------------------------------------------------------------
7120 Torque_check:  !  Checks if Haulback braking torque is exceeded
7130  !
7140     Line_out=SQR(Hl^2+Dl^2)+2*SQR(Hr^2+Dr^2)+15
7150     Line_in=1000-Line_out
7160     N_wraps=(SQR(Hbdiam^2*Line_in/(3.1416*Hbcorelength))-Hbcorerad)/Hbdia
m
7170     IF Skyline$="R" THEN
7180       Tension=2310/(INT(N_wraps)*Hbdiam+Hbdiam/2+Hbcorerad)
7190       IF Tension<Hbt THEN
7200         Hbt=Ta=Tension
7210       END IF
7220     ELSE
7230       Tension=1085/(INT(N_wraps)*Hbdiam+Hbdiam/2+Hbcorerad)
7240       IF Tension<Hbt THEN
7250         Hbt=T4=Tension
7260       END IF
7270     END IF
7280  RETURN
7290  ! ------------------------------------------------------------
7300 Yarding_sim:  !  Yarding simulation starts here
7310               PRINT "******* Skyline road # ",Sky_road_no
7320               Chok_len=5
7330               Eyd=Eydmin
7340               Area_got=Area_got+Eyd*Lat_dist/10000
7350               No_logs=0
7360               Temp_pieces=INT(Lat_dist*Eyd*Pieces/10000+0.5)
7370 Place_logs:   !
7380               IF No_logs<>Temp_pieces THEN
7390               Y_cor=RND*Eyd
```

```
7400              Side=RND
7410              IF Side>.5 THEN Side=-1*Side
7420              X_cor=Side*RND*Lat_dist
7430              GOSUB Assign       !  Assign a weight to the piece
7440              GOSUB Piece_in_or_out
7450 Next_piece:  GOTO 7380
7460              ELSE
7470              GOTO 7490
7480              END IF
7490         Min_wt=99999
7500         REDIM Yin(No_logs),Xin(No_logs),Log_wt(No_logs)
7510         MAT SORT Yin(*) TO Pointer
7520         MAT REORDER Yin BY Pointer
7530         MAT REORDER Xin BY Pointer
7540         MAT REORDER Log_wt BY Pointer
7550         FOR I=1 TO No_logs
7560            IF ABS(Log_wt(I))<Min_wt THEN Min_wt=ABS(Log_wt(I))
7570         NEXT I
7580         REDIM Yin(750),Xin(750),Log_wt(750)
7590         Point=1
7600 Build_turn:  !
7610         Log_pointer=1
7620         IF NOT Yin(Point) THEN Next_turn
7630         Log_one=Point  !ASSIGN FIRST LOG
7640         Kchok=1
7650         GOSUB Sky_yard_dist
7660         IF Log_wt(Log_one)>Avg_payload THEN
7670            IF Kchok=2 THEN
7680               No_too_big=No_too_big+1
7690               Vol_too_big=Vol_too_big+Log_wt(Log_one)
7700               IF Avg_payload=0 THEN
7710                 Ntb=Ntb+1
7720               END IF
7730               Kchok=1
7740               GOTO Next_turn
7750            ELSE
7760              Kchok=2
7770              GOTO 7650
7780            END IF
7790         END IF
7800         Turn_wt=Log_wt(Log_one)
7810         Nlog_turn=1
7820         Lyd=ABS(Xin(Log_one))
7830         IF (Avg_payload-Log_wt(Log_one)<Min_wt) THEN
7840            Yin(Log_one)=0
7850            GOTO Times
7860         END IF
7870         Aux_dist(Log_pointer)=0
7880         Aux_pntr(Log_pointer)=Log_one
7890         Log_pointer=Log_pointer+1
```

```
7900 Search_loop:    ! FIND ALL POSSIBLE LOGS
7910         FOR I=Point+1 TO No_logs
7920            IF Log_wt(Log_one)+Log_wt(I)>Avg_payload THEN I_next
7930            IF NOT Yin(I) THEN I_next
7940            IF Yin(I)>Yin(Log_one)+2*Chok_len THEN Sort_2
7950            Dist=SQR((Yin(Log_one)-Yin(I))^2+(Xin(Log_one)-Xin(I))^2)
7960            IF Dist>2*Chok_len THEN I_next
7970            Aux_dist(Log_pointer)=Dist
7980            Aux_pntr(Log_pointer)=I
7990            Log_pointer=Log_pointer+1
8000            IF Log_pointer>10 THEN Sort_2
8010 I_next: NEXT I
8020 Sort_2:!
8030         FOR I=1 TO Log_pointer-2
8040            FOR J=1 TO Log_pointer-1-I
8050               IF Aux_dist(J)<Aux_dist(J+1) THEN N_j
8060               Temp_dist=Aux_dist(J)
8070               Aux_dist(J)=Aux_dist(J+1)
8080               Aux_dist(J+1)=Temp_dist
8090               Temp_pntr=Aux_pntr(J)
8100               Aux_pntr(J)=Aux_pntr(J+1)
8110               Aux_pntr(J+1)=Temp_pntr
8120 N_j:       NEXT J
8130         NEXT I
8140 Pos_comb:      ! CHECK ALL POSSIBLE COMBINATIONS OF LOGS
8150         R=6              !   Number of chokers=6
8160         IF Log_pointer-1<R THEN R=Log_pointer-1
8170         N=Log_pointer-1
8180 Search_beg:   !
8190         FOR I=1 TO R
8200            Comb(I)=I
8210         NEXT I
8220         GOSUB Turn_check
8230         IF Gt_flag=1 THEN Times
8240 Iter_1:   !
8250         Comb(R)=Comb(R)+1
8260         IF Comb(R)>N THEN Iter_2
8270         GOSUB Turn_check
8280         IF Gt_flag=1 THEN Times
8290         GOTO Iter_1
8300 Iter_2:   !
8310         IF INT(R/2)+1=2 THEN Complete
8320         IF R-1<1 THEN Complete
8330         Comb(R-1)=Comb(R-1)+1
8340         IF Comb(R-1)>N THEN Iter_3
8350         Comb(R)=Comb(R-1)+1
8360         IF Comb(R)>N THEN Iter_3
8370         GOSUB Turn_check
8380         IF Gt_flag=1 THEN Times
8390         GOTO Iter_1
```

```
8400 Iter_3:       !
8410          IF INT(R/2)+1=3 THEN Complete
8420          IF R-2<1 THEN Complete
8430          Comb(R-2)=Comb(R-2)+1
8440          IF Comb(R-2)>N THEN Iter_4
8450          Comb(R-1)=Comb(R-2)+1
8460          IF Comb(R-1)>N THEN Iter_4
8470          Comb(R)=Comb(R-2)+2
8480          IF Comb(R)>N THEN Iter_4
8490          GOSUB Turn_check
8500          IF Gt_flag=1 THEN Times
8510          GOTO Iter_1
8520 Iter_4:       !
8530          IF INT(R/2)+1=4 THEN Complete
8540          IF R-3<1 THEN Complete
8550          Comb(R-3)=Comb(R-3)+1
8560          IF Comb(R-3)>N THEN Iter_5
8570          Comb(R-2)=Comb(R-3)+1
8580          IF Comb(R-2)>N THEN Iter_5
8590          Comb(R-1)=Comb(R-3)+2
8600          IF Comb(R-1)>N THEN Iter_5
8610          Comb(R)=Comb(R-3)+3
8620          IF Comb(R)>N THEN Iter_5
8630          GOSUB Turn_check
8640          IF Gt_flag=1 THEN Times
8650          GOTO Iter_1
8660 Iter_5:       !
8670          IF INT(R/2)+1=5 THEN Complete
8680          IF R-4<1 THEN Complete
8690          Comb(R-4)=Comb(R-4)+1
8700          IF Comb(R-4)>N THEN Iter_6
8710          Comb(R-3)=Comb(R-4)+1
8720          IF Comb(R-3)>N THEN Iter_6
8730          Comb(R-2)=Comb(R-4)+2
8740          IF Comb(R-2)>N THEN Iter_6
8750          Comb(R-1)=Comb(R-4)+3
8760          IF Comb(R-1)>N THEN Iter_6
8770          Comb(R)=Comb(R-4)+4
8780          IF Comb(R)>N THEN Iter_6
8790          GOSUB Turn_check
8800          IF Gt_flag=1 THEN Times
8810          GOTO Iter_1
8820 Iter_6:       !
8830          IF INT(R/2)+1=6 THEN Complete
8840          IF R-5<1 THEN Complete
8850          Comb(R-5)=Comb(R-5)+1
8860          IF Comb(R-5)>N THEN Complete
8870          Comb(R-4)=Comb(R-5)+1
8880          IF Comb(R-4)>N THEN Complete
8890          Comb(R-3)=Comb(R-5)+2
```

```
8900          IF Comb(R-3)>N THEN Complete
8910          Comb(R-2)=Comb(R-5)+3
8920          IF Comb(R-2)>N THEN Complete
8930          Comb(R-1)=Comb(R-5)+4
8940          IF Comb(R-1)>N THEN Complete
8950          Comb(R)=Comb(R-5)+5
8960          IF Comb(R)>N THEN Complete
8970          GOSUB Turn_check
8980          IF Gt_flag=1 THEN Times
8990          GOTO Iter_1
9000 Complete:      !
9010          R=R-1
9020          GOTO Search_beg
9030 Times:!
9040          IF Mach_size=0 THEN
9050                Cycle=3.743+0.0101*Syd+0.16*Nlog_turn+0.037*Turn_wt/Density
9060                Delays=0.925+1.301*Loc-0.00263*Loc*Syd
9070          ELSE
9080                Cycle=3.516+0.008*Syd+0.238*Nlog_turn+0.052*Turn_wt/Density
9090                Delays=2.46+0.14*Loc
9100          END IF
9110 Stats:   Cycle_sum=Cycle_sum+Cycle
9120          Cycle_sumsq=Cycle_sumsq+Cycle^2
9130          IF Cycle>Max_cycle THEN Max_cycle=Cycle
9140          IF Cycle<Min_cycle THEN Min_cycle=Cycle
9150          Cum_time=Cum_time+Delays+Cycle
9160          Turns=Turns+1
9170          Turnvol_sum=Turnvol_sum+Turn_wt/Density
9180          Turnvol_ssq=Turnvol_ssq+(Turn_wt/Density)^2
9190          IF Turn_wt/Density>Max_vol THEN Max_vol=Turn_wt/Density
9200          IF Turn_wt/Density<Min_vol THEN Min_vol=Turn_wt/Density
9210          Turnno_sum=Turnno_sum+Nlog_turn
9220          Turnno_ssq=Turnno_ssq+Nlog_turn^2
9230          IF Nlog_turn>Max_no THEN Max_no=Nlog_turn
9240          IF Nlog_turn<Min_no THEN Min_no=Nlog_turn
9250          Total_syd=Total_syd+Syd
9260 Next_turn:IF Log_wt(Log_one)>Avg_payload THEN Go_around
9270          IF Yin(Log_one) THEN Build_turn
9280 Go_around:Point=Point+1
9290          IF Point>No_logs THEN
9300             Cum_time=Cum_time+Rs_time
9310             GOTO 9350
9320          ELSE
9330             GOTO Build_turn
9340          END IF
9350   PRINT "TURNS,CYCLESUM,TURNVOLSUM",Turns,Cycle_sum,Turnvol_sum
9360          RETURN
9370 ! ----------------------------------------------------------------
9380 Assign: ! Assigns a weight to each log on the grid overlay
9390          Templog_wt=Aa+Bb*(ABS(LOG(1-RND)))^(1/Cc)
```

```
9400         Templog_wt=Density*Templog_wt
9410         RETURN
9420 ! ------------------------------------------------------------------
9430 Piece_in_or_out:  !  Checks whether the piece is within yarding triangle
9440         Bound_right=Lat_dist*Y_cor/Eyd
9450         Bound_left=-1*Bound_right
9460         IF X_cor>Bound_right OR X_cor<Bound_left THEN
9470            RETURN
9480         ELSE
9490            No_logs=No_logs+1
9500            Yin(No_logs)=Y_cor
9510            Xin(No_logs)=X_cor
9520            Log_wt(No_logs)=Templog_wt
9530         END IF
9540         RETURN
9550 ! -------------------------------------------------------------------
9560 Sky_yard_dist:  ! Subroutine to calculate skyline yarding distance
9570         IF Kchok=1 THEN
9580            Plus=0
9590         ELSE
9600            Plus=30
9610         END IF
9620         J=INT((Yin(Log_one)/Eyd)*25)+1
9630         IF J=1 THEN
9640            Syd=Yin(Log_one)
9650            Avg_payload=Payzone(1+Plus)
9660         ELSE
9670            Syd=0
9680            FOR Ii=2 TO J
9690            Grdist_temp=SQR((Prof(1,Ii)-Prof(1,Ii-1))^2+(Prof(2,Ii)-Prof(2
,Ii-1))^2)
9700            Syd=Syd+Grdist_temp
9710            NEXT Ii
9720            Extra=FRACT(25*Yin(Log_one)/Eyd)*Eyd/25
9730            Syd=Syd+Extra
9740            Avg_payload=Payzone(J+Plus)
9750            IF J=Tailspar THEN Avg_payload=Payzone(Tailspar-1+Plus)
9760         END IF
9770         RETURN
9780 ! ------------------------------------------------------------
9790 Turn_check:       ! GOSUB FOR CHECKING TURNS
9800         X_sum=Y_sum=Turn_wt=Gt_flag=0
9810         FOR I=1 TO R
9820            Turn_wt=Turn_wt+Log_wt(Aux_pntr(Comb(I)))
9830         NEXT I
9840         IF Turn_wt>Avg_payload THEN RETURN
9850         FOR I=1 TO R
9860            X_sum=X_sum+Xin(Aux_pntr(Comb(I)))
9870            Y_sum=Y_sum+Yin(Aux_pntr(Comb(I)))
9880         NEXT I
```

```
 9890          Ave_x=X_sum/R
 9900          Ave_y=Y_sum/R
 9910          FOR I=1 TO R
 9920             Ck_dist=SQR((Yin(Aux_pntr(Comb(I)))-Ave_y)^2+(Xin(Aux_pntr(Com
b(I)))-Ave_x)^2)
 9930             IF Ck_dist>Chok_len THEN RETURN
 9940          NEXT I
 9950          Lyd=ABS(Ave_x)
 9960          Nlog_turn=R
 9970          FOR I=1 TO R
 9980             Yin(Aux_pntr(Comb(I)))=0
 9990             Log_wt_sum=Log_wt_sum+Log_wt(Aux_pntr(Comb(I)))
10000          NEXT I
10010          Gt_flag=1
10020          RETURN
10030 ! ----------------------------------------------------------------
10040 Summary: !  Production summary for yarder
10050          IF Skyline$="R" THEN
10060             No_days_setting=(Cum_time/395)+0.75 ! 395 minutes/480 min. day
  plus 0.75 days for moving
10070          ELSE
10080             No_days_setting=(Cum_time/375)+0.75 ! 375 minutes/480 min. day
   plus 0.75 days for moving.
10090          END IF
10100          Ayd=Total_syd/Turns
10110          Ave_log_wt=Log_wt_sum/Turnno_sum
10120          Daily_prod=Turnvol_sum/No_days_setting
10130          Ave_cycle=Cycle_sum/Turns
10140          Ave_vol=Turnvol_sum/Turns
10150          Ave_no=Turnno_sum/Turns
10160          Vol_sd=SQR((Turnvol_ssq-Turnvol_sum^2/Turns)/(Turns-1))
10170          No_sd=SQR((Turnno_ssq-Turnno_sum^2/Turns)/(Turns-1))
10180          Cycle_sd=SQR((Cycle_sumsq-Cycle_sum^2/Turns)/(Turns-1))
10190          Settingvol=Turnvol_sum
10200          RETURN
10210 ! ----------------------------------------------------
10220 Costs:! Overall routine to calculate costs
10230        GOSUB Felling_costs
10240        GOSUB Yarding_costs
10250        GOSUB Process_costs
10260        GOSUB Loading_costs
10270        GOSUB Trucking_costs
10280        GOSUB Sortyard_costs
10290        GOSUB Landing_costs
10300        GOSUB Move_costs
10310        Unitcost=Unitlandcost+Unitfellcost+Unityardcost+Unitproccost+Unitlo
adcost+Unittruckcost+Unitsortcost+Unitmovecost
10320        RETURN
10330  ! -----------------------------------------------------------
10340 Felling_costs:  ! On a setting and per cubic metre basis.
```

```
10350       Labor_rate=100   ! $100 per day per man.
10360       Sawrate=23       ! $23 per day per saw.
10370       BEEP 2000,.05
10380       PRINT "Area harvested = ",Area_got
10390       PRINT "Volume too big = ",Vol_too_big/Density
10400       PRINT "Number too  big in zero payload areas = ",Ntb
10410       PRINT "Enter the following stand details as requested:"
10420       INPUT "Mean diameter breast height (cm) =",Dbh
10430       INPUT "Stocking (spha) =",Stemsperha
10440       INPUT "Pungas per hectare =",Pungas
10450       INPUT "Mean tree volume (m^3) =",Treevol
10460       INPUT "Average slope (degrees) =",Slope
10470       IF Man_loc=1 THEN
10480           Fell_time=(Stemsperha*(0.045*Dbh+0.01*Slope+0.139-0.00082*Stems
perha-0.00082*Pungas)+Pungas*(0.68+0.01*Slope))*1.32
10490       ELSE
10500           Fell_time=Stemsperha*(0.046*Dbh+0.01*Slope+2.292-0.00084*Stemsp
erha-0.00084*Pungas+2.967*Treevol-0.345*Treevol^2)+Pungas*(0.68+0.01*Slope)
10510           Fell_time=Fell_time*1.32
10520       END IF
10530       Totalfelltime=Fell_time*Area
10540       No_fallers=(Totalfelltime/480)/No_days_setting
10550   !
10560       Laborcost=(Totalfelltime/480)*Labor_rate
10570       Sawcost=(Totalfelltime/480)*Sawrate
10580       Fellcost=Laborcost+Sawcost   ! Setting costs for felling
10590       Unitfellcost=Fellcost/Settingvol
10600       RETURN
10610   ! ------------------------------------------------------------------
10620 Yarding_costs:   ! Calculates yarding costs on a per cubic metre basis
10630                  ! Includes gang transport & accessories, and equipment
accessories
10640       Yardlabor=4*100           ! 2 breaker-outs, 1 gang-boss, 1  yarder
operator. $100/man.
10650       Gang_transport=45         ! $/day
10660       Gang_accessory=56         ! $/day
10670       Equip_access=60           ! $/day
10680       IF Mach_size=0 THEN
10690          Capitalcost=1100000
10700          Machine=1              ! MADILL 009
10710       ELSE
10720          Capitalcost=820000
10730          Machine=2              ! MADILL 071
10740       END IF
10750          Resalevalue=0.1*Capitalcost
10760          Life=10
10770       GOSUB Machine_costs
10780       Yardcost=Yardlabor+Gang_transport+Gang_accessory+Equip_access+Daily
_mach_cost
10790       Unityardcost=Yardcost*No_days_setting/Settingvol
```

```
10800       RETURN
10810  ! --------------------------------------------------------------
10820 Process_costs:  ! For log manufacturing on a landing or unhooking and cle
anup
10830       IF Man_loc=1 THEN
10840            No_proc_days=3*No_days_setting      ! 3 men to unhook, delimb
and process
10850            No_proc_men=3
10860       ELSE
10870            No_proc_days=1*No_days_setting      ! 1 man to unhook and do
any cleanup delimbing.
10880            No_proc_men=1
10890       END IF
10900       Proc_cost=No_proc_days*(Labor_rate+Sawrate)
10910       Unitproccost=Proc_cost/Settingvol
10920       RETURN
10930  ! -------------------------------------------------------------------
10940 Loading_costs:   !  Calculates loading costs
10950       IF Man_loc=1 THEN
10960          Capitalcost=218000
10970          Life=5
10980          Machine=3        ! Rubber-tyred front end loader
10990       ELSE
11000          Capitalcost=434000
11010          Life=7
11020          Machine=4        ! Boom loader
11030       END IF
11040       Resalevalue=0.2*Capitalcost
11050       GOSUB Machine_costs
11060       Loadlabor=100
11070       Loadcost=Loadlabor+Daily_mach_cost
11080       Unitloadcost=Loadcost*No_days_setting/Settingvol
11090       RETURN
11100  ! ---------------------------------------------------------------
11110 Trucking_costs:   ! Calculates an average cost for truck haul for the
various products harvested.
11120       DISP "Enter the following information as requested:"
11130       Cpydist=0
11140       IF Man_loc<>2 THEN 11160
11150       INPUT "One way lead distance (km) to CPY",Cpydist
11160       INPUT "Number of product destinations",Npd
11170       Unittruckcost=0
11180       FOR I=1 TO Npd
11190       PRINT "One-way lead distance for product #",I
11200       INPUT Pdist(I)
11210       INPUT "Volume percentage in this product type",Volper
11220       Volper(I)=Volper/100
11230       INPUT "Product type name = ",Prodtype$(I)
11240       ! 10% additional cost is added to the Kaingaroa based equation for
steeper terrain in other parts of New Zealand.
```

```
11250      Unittruckcost=Unittruckcost+(Pdist(I)*.112192+1.54546)*1.1*Volper(I
)
11260      NEXT I
11270      IF Covdist=0 THEN 11290
11280      Unittruckcost=Unittruckcost+(Covdist*.112192+1.54546)*1.1
11290      RETURN
11300  ! ----------------------------------------------------------------
11310 Sortyard_costs:  !
11320      IF Man_loc=2 THEN
11330        Unitsortcost=7.25
11340      ELSE
11350        Unitsortcost=0
11360      END IF
11370      RETURN
11380  ! ----------------------------------------------------------------
11390 Landing_costs:  ! Cost of landing construction for the setting
11400      IF Man_loc=1 THEN
11410         Landcost=15000
11420      ELSE
11430         Landcost=2500
11440      END IF
11450      Unitlandcost=Landcost/Settingvol
11460      RETURN
11470  ! ----------------------------------------------------------------
11480 Move_costs:   ! Cost of moving into and out of a setting.
11490      Movecost=((No_fallers+No_proc_men)*123+Yardcost+Loadcost)*0.75
11500  !-------   Allows 0.75 days to move in and out.
11510      Unitmovecost=Movecost/Settingvol
11520      RETURN
11530  ! ----------------------------------------------------------------
11540 Machine_costs:  ! General machine costing routine
11550      Aci=(Capitalcost-Resalevalue)*(Life+1)/(2*Life)+Resalevalue
11560      Insurance=0.0215*Aci    ! 2.15% of Average capital invested
11570      Interest=Aci*(0.05*((0.12*1.12^Life)/(1.12^Life-1))+0.95*((0.14*1.1
4^Life)/(1.14^Life-1)))
11580      ! Interest rate based on 5% own funds at 12%pa plus 95% loan funds
at 14%pa.
11590      Returnoncapital=Aci*0.2     !   20% of ACI
11600      Adminoverheads=Aci*0.05     !    5% of ACI
11610      Depreciation=(Capitalcost-Resalevalue)/Life
11620      Randm=0.7*Depreciation      !    70% of depreciation
11630      Tyres=0
11640      Wires=0
11650      ON Machine GOTO 11660,11690,11720,11750
11660      Fuel_rate=83      ! litres per hour for Madill 009
11670      Wires=9050
11680      GOTO 11760
11690      Fuel_rate=52      ! Madill 071
11700      Wires=7250
11710      GOTO 11760
```

```
11720       Fuel_rate=22     ! Rubber-tyred front end loader
11730       Tyres=4000
11740       GOTO 11760
11750       Fuel_rate=31     ! Boom loader
11760       Fuel=0.77*6*Fuel_rate ! $0.77/litre, 6 hours/day
11770       Lubricants=0.07*Fuel  !  7% of fuel costs
11780       Daily_mach_cost=(Insurance+Interest+Returnoncapital+Adminoverheads+
Randm+Depreciation+Tyres+Wires)/220+Fuel+Lubricants
11790       RETURN
11800   ! -------------------------------------------------------------
11810 Output:  ! Overall control of reporting section of the program
11820     PRINTER IS Print_add
11830     GOSUB Out_header
11840     GOSUB Out_system
11850     GOSUB Out_stand
11860     GOSUB Out_yard_prod
11870     GOSUB Out_header
11880     GOSUB Out_trucking
11890     GOSUB Out_costs
11900     RETURN
11910  ! -------------------------------------------------------------
11920 Out_header:  !  Title for report
11930     PRINT PAGE
11940     PRINT TAB(25);"=============================="
11950     PRINT TAB(25);"PROCESSING OPTIONS SIMULATION"
11960     PRINT TAB(25);"==============================",LIN(1)
11970     PRINT TAB(5);Rn$,"                                   ",Date$,LIN(2
)
11980     RETURN
11990  ! -------------------------------------------------------------
12000 Out_system:  !
12010     PRINT "System information"
12020     PRINT "==================",LIN(1)
12030     ON Man_loc+1 GOTO 12040,12060,12080
12040     PRINT "Log processing carried out at the stump."
12050     GOTO 12090
12060     PRINT "Log processing carried out on a landing."
12070     GOTO 12090
12080     PRINT "Log processing partially carried out at the stump and then com
pleted at a       Central Processing Yard."
12090     ON Mach_size+1 GOTO 12100,12120
12100     PRINT "Yarding machine was a Madill 009 rigged as a Grabinski skyline
."
12110     GOTO 12130
12120     PRINT "Yarding machine was a Madill 071 rigged as a Slackline."
12130     IF Man_loc=1 THEN
12140        PRINT "Loading was with a medium-sized rubber tyred front end load
er.",LIN(1)
12150     ELSE
12160        PRINT "Loading was with a medium-sized hydraulic boom loader.",LIN
```

(1)

```
12170      END IF
12180      RETURN
12190   ! -----------------------------------------------------------------
12200 Out_stand:   !
12210      PRINT "Stand and setting information"
12220      PRINT "=============================",LIN(1)
12230      PRINT "Mean diameter breast height (cm) = ",Dbh
12240      PRINT "Stocking (stems per hectare)     = ",Stemsperha
12250      PRINT "Mean tree volume (cubic metres)  = ",Treevol
12260      PRINT "Live stand volume (m^3/ha)       = ",Treevol*Stemsperha
12270      PRINT "Pungas per hectare               = ",Pungas,LIN(1)
12280      PRINT USING Look_1;Area
12290 Look_1: IMAGE "The setting was irregular shaped and was ",3D.D," hectares
in area."
12300      PRINT LIN(2)
12310      RETURN
12320   ! ---------------------------------------------------------------------
12330 Out_yard_prod:   !
12340      PRINT "Yarding and cycle statistics"
12350      PRINT "============================",LIN(1)
12360      PRINT USING Look_2;Daily_prod
12370      PRINT USING Look_3;(No_days_setting)
12380      PRINT "The number of skyline road changes was ",Sky_road_no
12390      PRINT "The number of yarding cycles was ",Turns
12400      PRINT USING Look_5:Ave_log_wt
12410      PRINT USING Look_18;No_too_big,Vol_too_big/1000
12420      PRINT USING Look_4;Ayd
12430      PRINT USING Look_20;Settingvol
12440      PRINT LIN(1)
12450      PRINT TAB(28),"   Mean      Std dev   Minimum   Maximum",LIN(1)
12460      PRINT USING Look_6;Ave_vol,Vol_sd,Min_vol,Max_vol
12470      PRINT USING Look_7;Ave_no,No_sd,Min_no,Max_no
12480      PRINT USING Look_8;Ave_cycle,Cycle_sd,Min_cycle,Max_cycle
12490      PRINT LIN(1)
12500 Look_2:  IMAGE "Daily yarding production was ",DDD.D," cubic metres."
12510 Look_3:  IMAGE "It took ",3D.D," days to harvest the setting."
12520 Look_4:  IMAGE "The average yarding distance was ",DDD.D," metres."
12530 Look_5:  IMAGE "The average log weight was ",5D.D," kilograms"

12540 Look_6:  IMAGE 7X,"Cycle volume (m^3)",3X,5D.DD,1X,5D.DD,2X,5D.DD,2X,5D.D
D
12550 Look_7:  IMAGE 7X,"Number of logs",7X,5D.DD,1X,5D.DD,2X,5D.DD,2X,5D.DD
12560 Look_8:  IMAGE 7X,"Cycle time   (Min)",3X,5D.DD,1X,5D.DD,2X,5D.DD,2X,5D.D
D
12570 Look_18:  IMAGE 3D," logs (totalling ",4D.D," cubic metres) were too big
to be yarded uncut."
12580 Look_20:  IMAGE "Total volume extracted was ",6D.D," cubic metres."
12590           RETURN
12600   ! ------------------------------------------------------------------
```

```
12610 Out_trucking:   !
12620          PRINT "Trucking information"
12630          PRINT "====================",LIN(1)
12640          FOR I=1 TO Npd
12650          PRINT "One-way lead distance for ",Prodtype$(I),"logs was ",Pdis
t(I)," kilometres."
12660          PRINT Volper(I)*100," % of the total volume was trucked as this
product type.",LIN(1)
12670          NEXT I
12680          RETURN
12690  ! --------------------------------------------------------------
12700 Out_costs:  !
12710          PRINT "Cost information"
12720          PRINT "================",LIN(1)
12730          PRINT TAB(25);"Setting      Hectare      Cubic metre"
12740          PRINT LIN(1)
12750          PRINT USING Look_9;Fellcost,Fellcost/Area,Unitfellcost
12760          PRINT USING Look_10;Yardcost*No_days_setting,Yardcost*No_days_se
tting/Area,Unityardcost
12770          PRINT USING Look_11;Proc_cost,Proc_cost/Area,Unitproccost
12780          PRINT USING Look_12;Loadcost*No_days_setting,Loadcost*No_days_se
tting/Area,Unitloadcost
12790          PRINT USING Look_13;Unittruckcost*Settingvol,Unittruckcost*Setti
ngvol/Area,Unittruckcost
12800          PRINT USING Look_14;Unitsortcost*Settingvol,Unitsortcost*Setting
vol/Area,Unitsortcost
12810          PRINT USING Look_15;Movecost,Movecost/Area,Unitmovecost
12820          PRINT USING Look_16;Landcost,Landcost/Area,Unitlandcost
12830          PRINT LIN(1)
12840          PRINT USING Look_17;Unitcost*Settingvol,Unitcost*Settingvol/Area
,Unitcost
12850 Look_9:   IMAGE "Falling",19X,7D,6X,7D,9X,2D.DD
12860 Look_10:   IMAGE "Yarding",19X,7D,6X,7D,9X,2D.DD
12870 Look_11:   IMAGE "Processing",16X,7D,6X,7D,9X,2D.DD
12880 Look_12:   IMAGE "Loading",19X,7D,6X,7D,9X,2D.DD
12890 Look_13:   IMAGE "Trucking",18X,7D,6X,7D,9X,2D.DD
12900 Look_14:   IMAGE "Sortyard",18X,7D,6X,7D,9X,2D.DD
12910 Look_15:   IMAGE "Move in/Move out",10X,7D,6X,7D,9X,2D.DD
12920 Look_16:   IMAGE "Landing Construction",6X,7D,6X,7D,9X,2D.DD
12930 Look_17:   IMAGE "Total",21X,7D,6X,7D,9X,2D.DD
12940           RETURN
12950 !
12960 !************************** SUBPROGRAMS **********************************
12970 !
12980        SUB Name_that_dtm(Dtmstore$,Dir$,Msus$,Z$)
12990 !
13000 Name_that_dtm:!
13010 !
13020 ! --> Name_that_dtm TRIES TO FIND A REQUESTED DTM FILE.
13030 !
```

```
13040          OPTION BASE 1
13050          DIM Cat$(2)[80]
13060          Msus$=":CS80,5"
13070          Dir$="Plans_dtm/"
13080 !
13090 ! --> TRY TO ACCESS THE DTM FILE
13100 !
13110 First_try:ASSIGN #1 TO "Plans_dtm/"&Z$&Msus$;RETURN Error
13120 !
13130 ! --> IF SUCCESSFUL SET Dtmstore$ AND RETURN TO MAIN
13140 !
13150          IF NOT Error THEN
13160             Dir$="Plans_dtm/"
13170             Dtmstore$="Plans_dtm/"&Z$&Msus$
13180             ASSIGN #1 TO *
13190             SUBEXIT
13200          END IF
13210          PRINT LIN(25);Z$;" IS NOT IN THE Plans_dtm DIRECTORY ON THE H
ARD"
13220          PRINT "DISK DRIVE."
13230          STOP
13240       SUBEND
13250 !-----------------------------------------------------------------------
13260 !
13270       SUB Getdtm(Xlines,Ylines,INTEGER G(*),Z$,Dtmstore$)
13280 !
13290 Getdtm:!
13300 !
13310 ! --> Getdtm READS THE ACTUAL GRIDDED DATA FROM THE DTM FILE
13320 !
13330          OPTION BASE 1
13340          ALLOCATE INTEGER Temp(Ylines)
13350          ASSIGN @A TO Dtmstore$;FORMAT OFF     !OPENS FILE
13360          FOR T2=2 TO Xlines+1
13370             ENTER @A,T2;Temp(*)
13380             FOR T3=1 TO Ylines
13390                G(T2-1,T3)=ABS(Temp(T3))
13400             NEXT T3
13410          NEXT T2
13420          ASSIGN @A TO *                        !CLOSES FILE
13430       SUBEND
13440 !
13450 !-----------------------------------------------------------------------
13460 !
13470       SUB Fill_holes(Xlines,Ylines,INTEGER G(*))
13480 !
13490 Fill_holes:!
13500 !
13510 ! --> Fill_holes FILLS ANY HOLES THAT MAY BE IN THE GRIDDED DTM DATA.
13520 ! --> HOLES ARE POINTS OR AREAS WITH ELEVATIONS OF 0 FEET.
```

```
13530 !
13540          OPTION BASE 1
13550          DEG
13560          DISP "STAND BY --- CONDITIONING DTM MATRIX --- STAND BY"
13570 !
13580 ! --> SCAN ACROSS THE DTM THEN UP THE DTM
13590 !
13600          FOR Xline=1 TO Xlines
13610            FOR Yline=1 TO Ylines
13620 !
13630 ! --> WHEN A HOLE (ELEVATION=0) IS FOUND, FILL IT
13640 !
13650               IF NOT G(Xline,Yline) THEN  GOSUB Fill
13660            NEXT Yline
13670          NEXT Xline
13680          DISP
13690          SUBEXIT
13700 !
13710 Fill:    J=1
13720 !
13730 ! --> SCAN THE DTM TO THE RIGHT , UP, OR DIAGONALLY TO FIND GOOD POINTS
13740 !
13750          REPEAT
13760 !
13770 ! --> IF ON THE SIDE OR TOP OF THE DTM, USE THE ELEVATION TO THE LEFT
13780 ! --> OF THE HOLE OR BELOW THE HOLE
13790 !
13800            IF Xline+J>Xlines THEN Back1
13810            IF Yline+J>Ylines THEN Back2
13820 !
13830 ! --> LOOK TO THE RIGHT OF HOLE, IF THERE IS AN ELEVATION THERE, USE IT
13840 !
13850            IF G(Xline+J,Yline) THEN Use1
13860 !
13870 ! --> LOOK ABOVE THE HOLE, IF THERE IS AN ELEVATION THERE, USE IT
13880 !
13890            IF G(Xline,Yline+J) THEN Use2
13900 !
13910 ! --> LOOK DIAGONALLY UP AND TO THE RIGHT, IF THERE IS AN ELEVATION THERE
13920 ! --> USE IT
13930 !
13940            IF G(Xline+J,Yline+J) THEN Use3
13950            J=J+1
13960          UNTIL J>297
13970 !
13980 Back1:   G(Xline,Yline)=G(Xline-1,Yline)
13990          RETURN
14000 Back2:   G(Xline,Yline)=G(Xline,Yline-1)
14010          RETURN
14020 Use1:    G(Xline,Yline)=G(Xline+J,Yline)
```

```
14030            RETURN
14040 Use2:      G(Xline,Yline)=G(Xline,Yline+J)
14050            RETURN
14060 Use3:      G(Xline,Yline)=G(Xline+J,Yline+J)
14070            RETURN
14080         SUBEND
14090 !
14100 !-------------------------------------------------------------------
14110 !
14120         SUB Periph_check(INTEGER Print_add,Dig_add)
14130 !
14140 Periph_check:!
14150 !
14160 ! --> Periph_check PERFORMS A SERIAL POLL ON THE PRINTER AND DIGITIZER
14170 ! --> TO SEE IF THEY ARE ACTIVE
14180 !
14190            OPTION BASE 1
14200            DIM Device$[12]
14210            INTEGER Dummy
14220            ON TIMEOUT 4,.25 GOTO Dev_out
14230 Device_loop:Device$="PRINTER"
14240            Sp=SPOLL(Print_add)
14250            Device$="DIGITIZER"
14260            Sp=SPOLL(Dig_add)
14270            OFF TIMEOUT 4
14280            SUBEXIT
14290 Dev_out:!
14300            DISP "PLEASE TURN ON THE ";Device$;", THEN PRESS RETURN";
14310            INPUT "",Dummy
14320            GOTO Device_loop
14330         SUBEND
14340 !
14350 !-------------------------------------------------------------------
14360 !
14370         SUB Active_check(INTEGER Dig_add)
14380 !
14390 Active_check:!
14400 !
14410 ! --> Active_check LOOKS TO SEE IF THE DIGITIZER CURSOR IS WITHIN THE
14420 ! --> DIGITIZER'S ACTIVE SURFACE ... IF NOT IT ASKS THE USER TO MOVE
14430 ! --> THE CURSOR TO THE ACTIVE SURFACE
14440 !
14450            ON TIMEOUT Dig_add,.2 GOTO Move_cur
14460            I=1
14470            REPEAT
14480 Get_point:ENTER Dig_add USING "#,K,K,A,A,A";X,Y,A$,Mode$,Button$
14490            I=I+1
14500            UNTIL I>50
14510            OFF TIMEOUT Dig_add
14520            SUBEXIT
```

```
14530 Move_cur: DISP "MOVE DIGITIZER'S CURSOR ONTO THE ACTIVE DIGITIZING AREA.
THEN PRESS RETURN";
14540           INPUT "",Dummy
14550           GOTO Get_point
14560         SUBEND
14570 !
14580 !----------------------------------------------------------------------
14590 !
14600         SUB Set_dig(Mode$)
14610 !
14620 Set_dig:!
14630 !
14640 ! --> Set_dig RESETS THE DIGITIZER, SETS IT TO THE DESIRED MODE, AND
14650 ! --> TURNS OFF CURSOR CONTROL
14660 !
14670           OPTION BASE 1
14680           COM U,V,Xlines,Ylines,Map_s,Sin,Cos,X0,Y0,Digit,Z$,Msus$,INTEGE
R Print_add,Dig_add
14690           ASSIGN @Dig TO Dig_add
14700           Cmd_fmt$="#,"&CHR$(34)&CHR$(27)&"%"&CHR$(34)&",A,/"
14710           Mode$=Mode$[1,1]
14720           OUTPUT @Dig USING "#,"&CHR$(34)&CHR$(27)&"%"&CHR$(34)&",2A,/";"
VR"
14730           SELECT Mode$
14740           CASE "P"!Point mode-one coord set when cursor key pressed
14750             OUTPUT @Dig USING Cmd_fmt$;"P"
14760           CASE "R"!Run-continuous stream of coordinate points
14770             OUTPUT @Dig USING Cmd_fmt$;"R"
14780           CASE "I"!Increment-
14790             OUTPUT @Dig USING Cmd_fmt$;"I"
14800           CASE "T"!Track-
14810             OUTPUT @Dig USING Cmd_fmt$;"T"
14820           CASE "L"!Line-
14830             OUTPUT @Dig USING Cmd_fmt$;"L"
14840           END SELECT
14850           OUTPUT @Dig USING Cmd_fmt$;"K"
14860         SUBEND
14870 !
14880 !----------------------------------------------------------------------
14890 !
14900         SUB Digit(X,Y,A$,Mode$,Button$)
14910 !
14920 Digit:!
14930 !
14940 ! --> Digit GETS POINT FROM THE DIGITIZER
14950 !
14960           OPTION BASE 1
14970           COM U,V,Xlines,Ylines,Map_s,Sin,Cos,X0,Y0,Digit,Z$,Msus$,INTEGE
R Print_add,Dig_add
14980           ENTER Dig_add USING "#,K,K,A,A,A";X,Y,A$,Mode$,Button$
```

```
14990        SUBEND
15000 !
15010 !------------------------------------------------------------------------
15020 !
15030        SUB Flush_digit(Button$)
15040 !
15050 Flush_digit:!
15060 !
15070 ! --> Flush_digit CLEARS THE DIGITIZER'S BUFFER OF UNWANTED POINTS
15080 !
15090 Begin_flush:Cnt=0
15100           REPEAT
15110              CALL Digit(X,Y,A$,Mode$,Button$)
15120              Cnt=Cnt+1
15130              IF Cnt>100 THEN
15140                 DISP "    *** PLEASE PRESS THE RESET BUTTON ON THE DIGIT
IZER, THEN PRESS RETURN ***   ";
15150                 INPUT "",Dummy
15160                 CALL Set_dig("R")
15170                 GOTO Begin_flush
15180              END IF
15190           UNTIL Button$="U"
15200        SUBEND
15210  ! ----------------------------------------------------------
```

APPENDIX B. Detailed description of PROSIM model

B.1 Digital Terrain Model Location

The PLANS computer package had many subprograms and subroutines which performed some of the functions needed in the PROSIM model. Rather than "reinvent the wheel" applicable subroutines were copied from PLANS and incorporated directly into PROSIM. The routines in PROSIM which handle loading and error checking of the DTM data and location of the DTM on the digitizing tablet fall into this category.

The user places the map from which the DTM was built on the digitizing tablet, enters the name of the DTM and then digitizes the location of the bottom left and bottom right corners of the DTM.

B.2 Landing location

The landing location is digitized and co-ordinates calculated (Figure B-1).

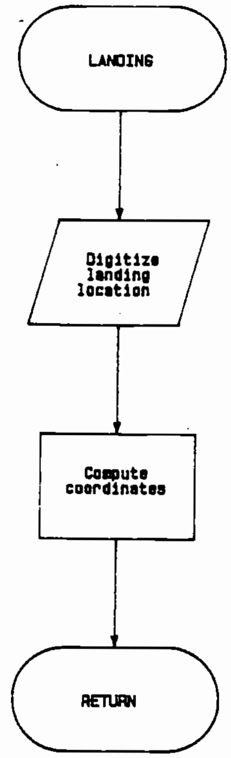

Figure B-1   Flowchart of landing location subroutine.

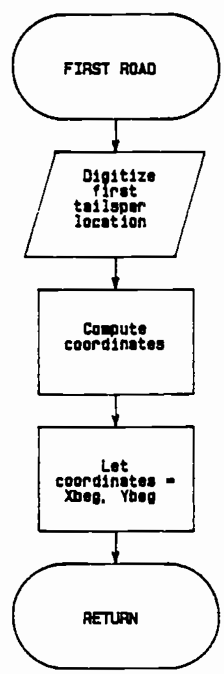

Figure B-2   Flowchart of first tailspar location subroutine.

B.3 First tailspar location

The location of the first tailspar is digitized and coordinates calculated (Figure B-2). The location of the first tailspar is marked for future reference so that PROSIM can determine when the whole setting has been harvested. The location of the first tailspar, and thus the first terrain profile, determines the location of all of the profiles on the harvest unit. Payload capability is dependent on individual terrain profiles. Daily yarding productivity may, therefore, vary depending on the location of the first tailspar.

B.4 Marking the harvest unit boundary

The boundary or perimeter of the harvest unit is marked with the digitizer, starting and finishing at the first tailspar location (Figure B-3). PROSIM only models an irregularly shaped harvest unit where all volume flows into a central landing. The central landing is assumed to be within the perimeter of the harvest unit. The whole harvest unit is assumed to be stocked with timber which will be logged, that is, there are no unmerchantable areas within the harvest unit and all tailspars lie on the harvest unit boundary.

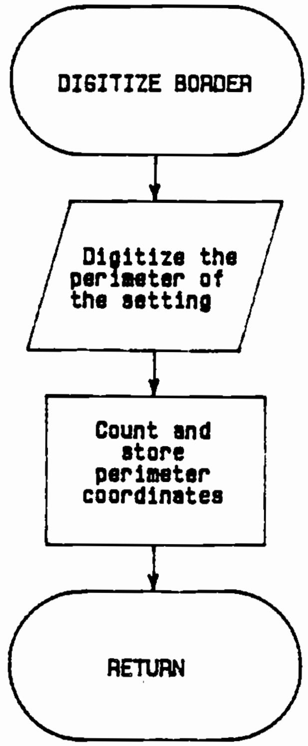

Figure B-3 Flowchart of subroutine to mark the perimeter of the harvest unit.

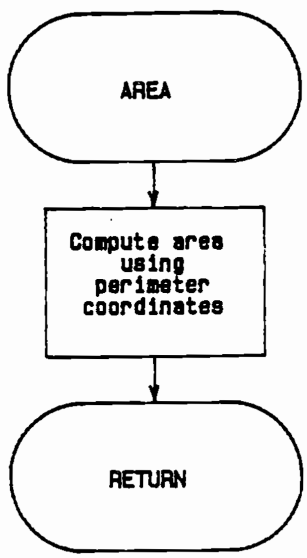

Figure B-4 Flowchart of subroutine to calculate the area of the harvest unit.

B.5 Area calculation

The area calculation subroutine was copied from the PLANS program and metricated (Figure B-4). A description of a similar algorithm used to calculate the area of irregularly shaped objects is given by Stolk and Ettershank (1987).

B.6 Logging system parameters

Figure B-5 depicts the flowchart for the LOGGING SYS subroutine. The model was originally written with just two yarding machines in mind; a Madill 009 rigged as a Grabinski skyline (Figure B-6) and a Madill 071 rigged as a slack skyline system (Figure B-7). These are two of the most common mobile yarders in New Zealand. Recently two Washington 88 running skyline yarders (Figure B-8) were brought into New Zealand. This type of yarder was also modeled by making minor changes to the original program.

B.6.1 Machine type and yarding parameters

The user first enters the type of machine to be modeled; either large (the Madill 009 rigged as a Grabinski or Washington 88 as a running skyline) or

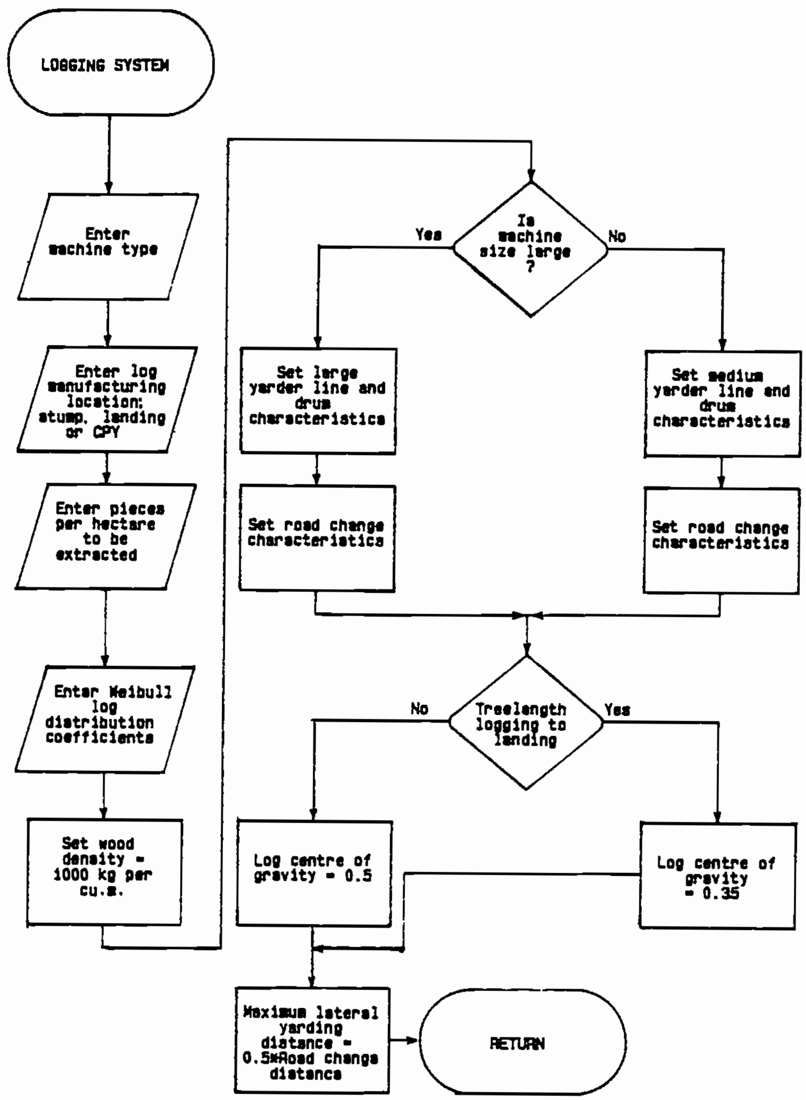

Figure B-5 Flowchart of subroutine to enter and set logging system parameters.

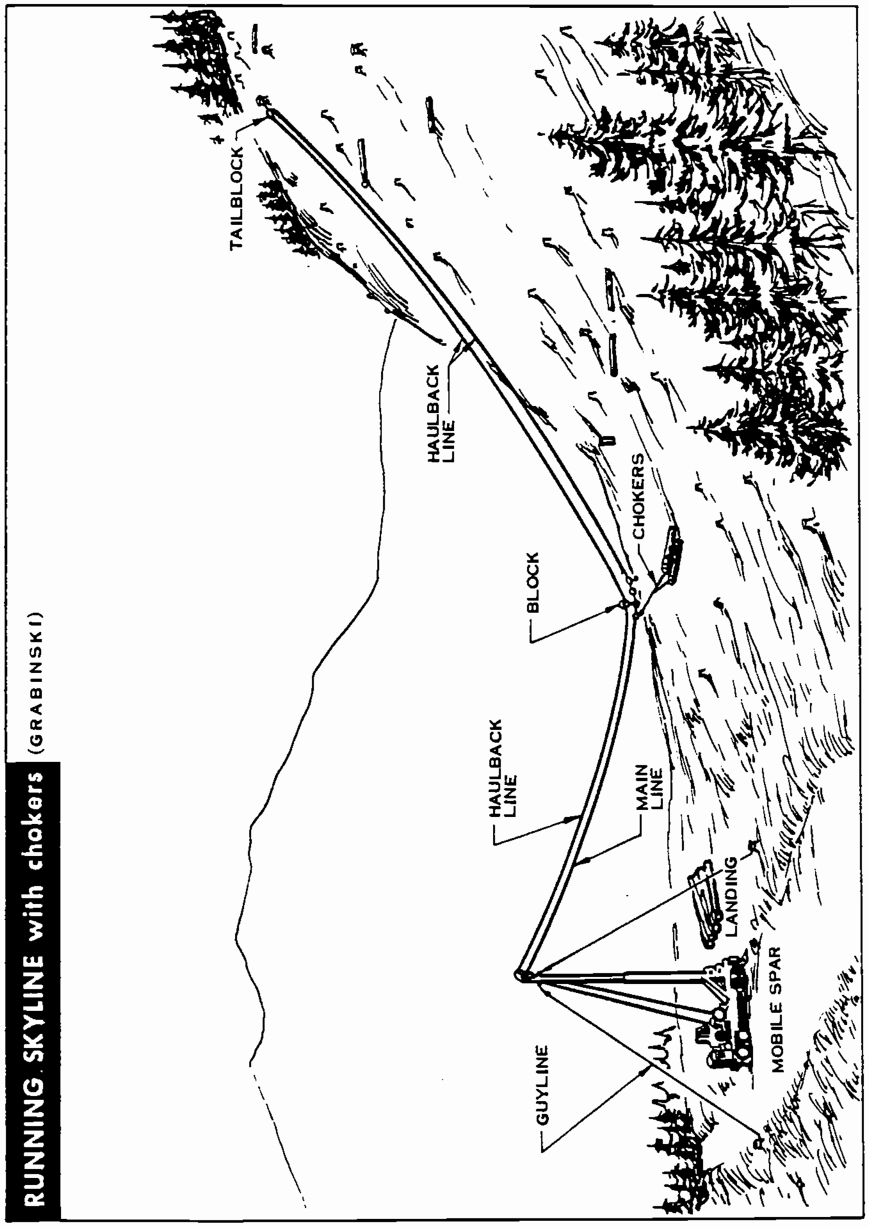

Figure B-6   Grabinski skyline.

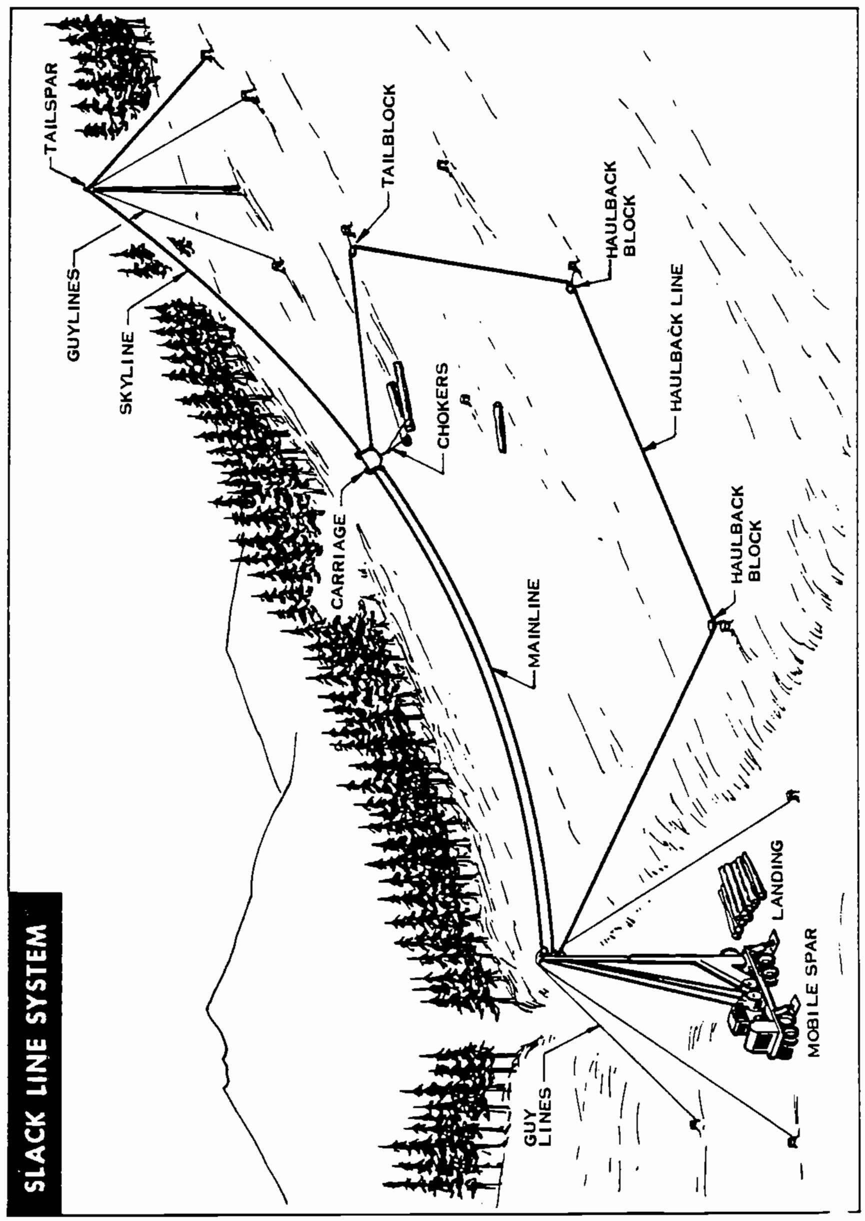

Figure B-7 Slack skyline system.

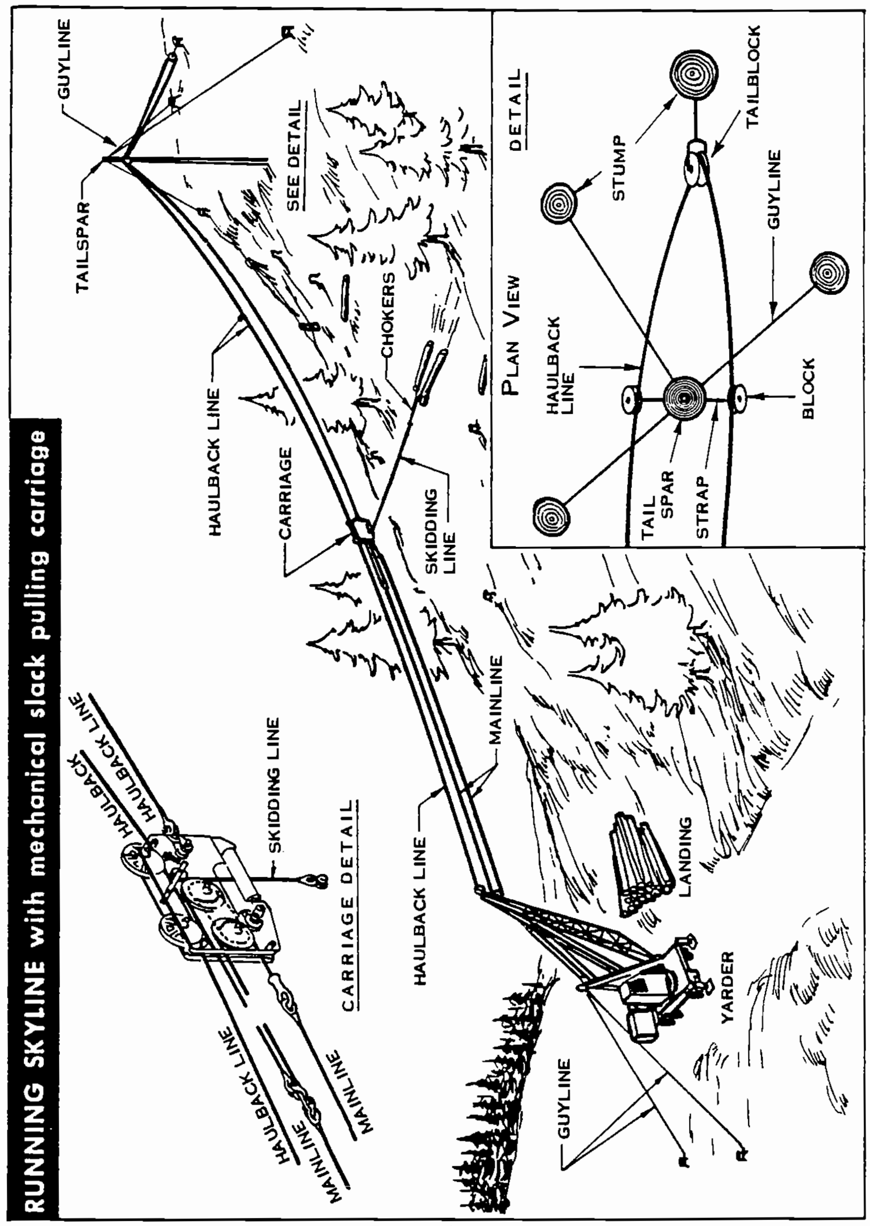

Figure B-8   Running skyline system.

medium (the Madill 071 rigged as a slack skyline). Dependent on the machine type selected certain yarding machine parameters are set by the model. Table B-1 lists the values set in this subroutine as a result of selecting the machine type.

Tower heights and drum characteristics were taken from manufacturers' specification sheets. Line weights and allowable tensions were taken from Studier and Binkley (1974) and metricated. The allowable tensions are based on a factor of safety of 3.0 of the ultimate strength of the lines. Although Sessions and others (1985) have suggested basing the factor of safety on economic criteria which might vary from country to country or logging operation to logging operation, the factor of safety incorporated in Studier and Binkley's data was accepted and used.

The maximum lateral yarding distance is set equal to half the skyline road change distance. Skyline road change times and distances will be discussed in detail in section B.10.

B.6.2 Log manufacturing location

The user then indicates where the final manufacturing (or processing) of the logs will be carried out; at the stump, on a large landing, or at a central

Table B-1 Yarding machine parameters set by PROSIM

Yarder Parameter	Madill 009	Madill 071	Washington 88
Headspar height (m)	27	14	14.4
Tailspar height (m)	1	1	1
Haulback weight (kg/m)	2.13	1.08	1.56
Mainline weight (kg/m)	4.33	2.13	3.13
Skyline weight (kg/m)	-	2.78	-
Haulback tension (kg-f)	12000	6200	8900
Mainline tension (kg-f)	24000	12000	8900
Skyline tension (kg-f)	-	15500	-
Haulback diameter (m)	0.022	0.016	0.019
Haulback drum core length (m)	0.74	0.533	0.80
Haulback drum core radius (m)	0.255	0.178	0.425
Carriage weight (kg)	250	200	210
Skyline road change time (minutes)	30	75	35
Road change distance (m)	13.5	15	30

processing yard. The selection determines program flow through many of the later subroutines.

If processing is carried out on a landing the program sets the centre of gravity of each piece equal to 35% of the piece length measured from the butt end. The location of the centre of gravity for tree length radiata pine has been studied by Wells (1982). The location of the log centre of gravity is used in payload calculations in the CLAP subroutine.

If processing is carried out at the stump or at a central processing yard (after pre-processing) the centre of gravity is set to 50% of the piece length. This is based on the assumption that small logs approximate a homogeneous cylinder.

B.6.3 Log size parameters

The user then enters the number of pieces per hectare to be extracted from the harvest unit. In this study this figure was obtained as an output from the value recovery studies described in Chapters 3 and 4. It could also be obtained from the MARVL stand assessment of the harvest unit (Deadman and Goulding, 1979).

PROSIM then requests the user to enter three coefficients from a three parameter weibull distribution of log size. Log distributions on harvest settings have usually been modeled either as exponential distributions for logs manufactured at the stump (Peters, 1973; Giles, 1986) or normal distributions for treelength logs (Sessions, 1979). The problem with the exponential distribution is that very small logs have a high probability of occurrence unless a truncated distribution is used (Figure B-9).

The three parameter weibull distribution models <u>both</u> treelength and log-length size distributions well (Figure B-10) and was therefore selected for use in PROSIM. Computer programs, such as WEIBULL, written for IBM-PC compatible computers (Torres-Rojo, 1987), can be used to generate the coefficients. The log size data required to generate the coefficients could be obtained from representative field samples, MARVL assessments, or as in the case of this study, as a by-product from value recovery studies.

The cumulative frequency function for log size for the three parameter weibull distribution takes the form:

F(logsize) = 1-exp[-((logsize-a)/b)**c]

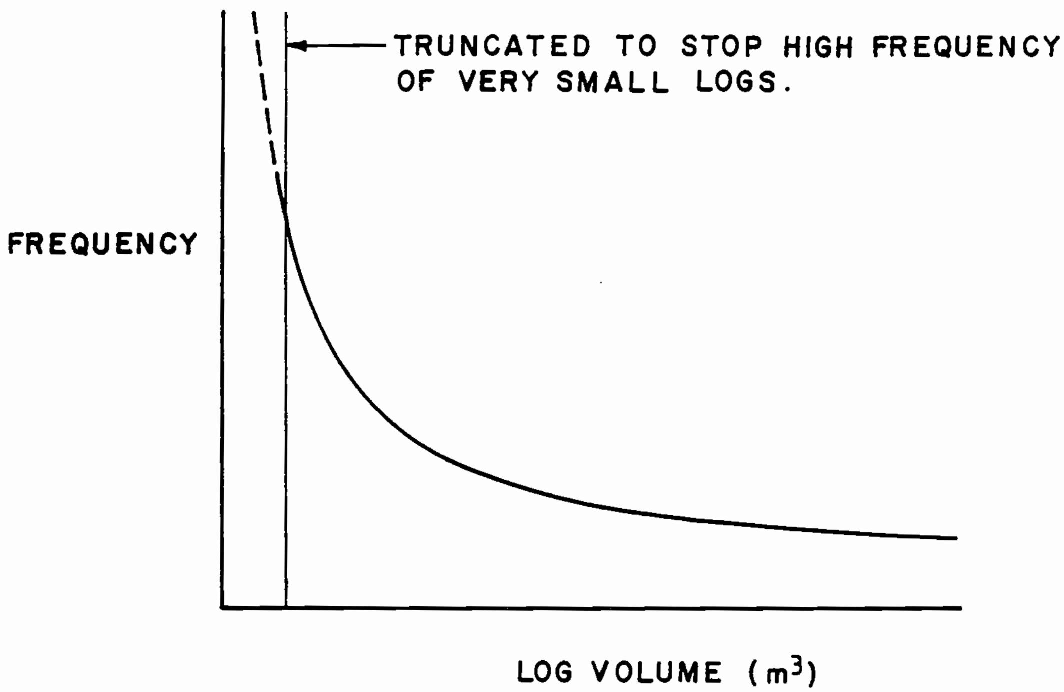

Figure B-9 Exponential distribution.

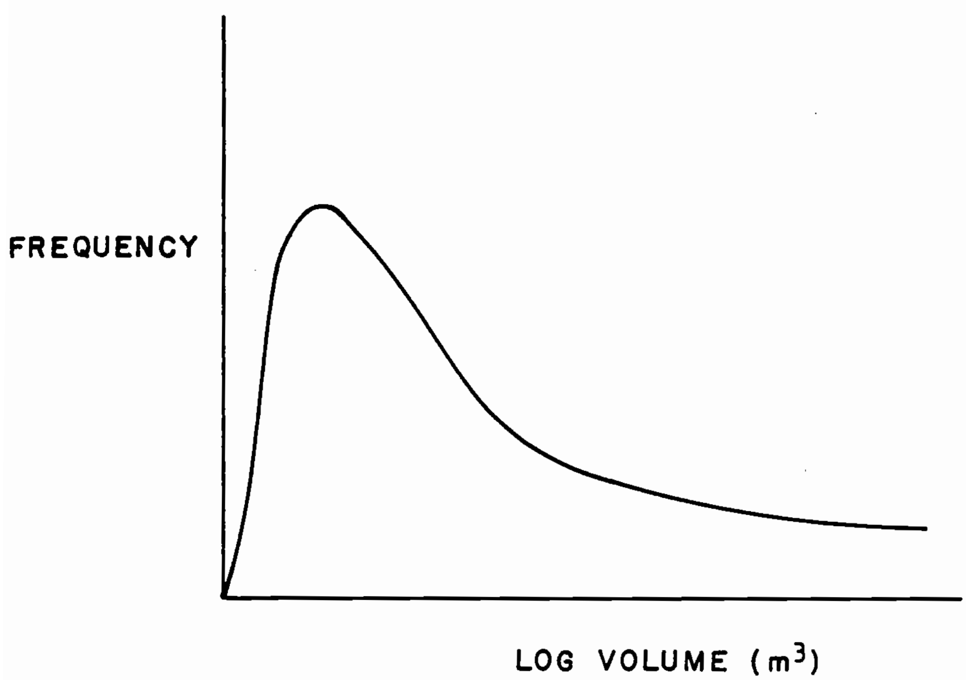

Figure B-10 Weibull distribution.

where; F(logsize) is the cumulative frequency of all logs up to the logsize specified,

and a, b, and c are distribution coefficients.

The three distribution coefficients are the values to be entered into PROSIM.

Ellis (1984) has found that weight/volume conversion factors for radiata pine in New Zealand vary between 970 and 1170 kilograms per cubic metre. He has suggested that a realistic long term national average would be about 1040 kilograms per cubic metre. In PROSIM the wood density is set equal to 1000 kilograms per cubic metre.

B.7 New tailspar location

If the first skyline road has not been logged the main program skips over this subroutine and uses the first tailspar coordinates entered by using the digitizer.

Figure B-11 shows the flowchart for the NEW TAILSPAR subroutine. Simple linear algebra formulae are used to determine the location of the new tailspar on the harvest unit boundary. The calculations are dependent on

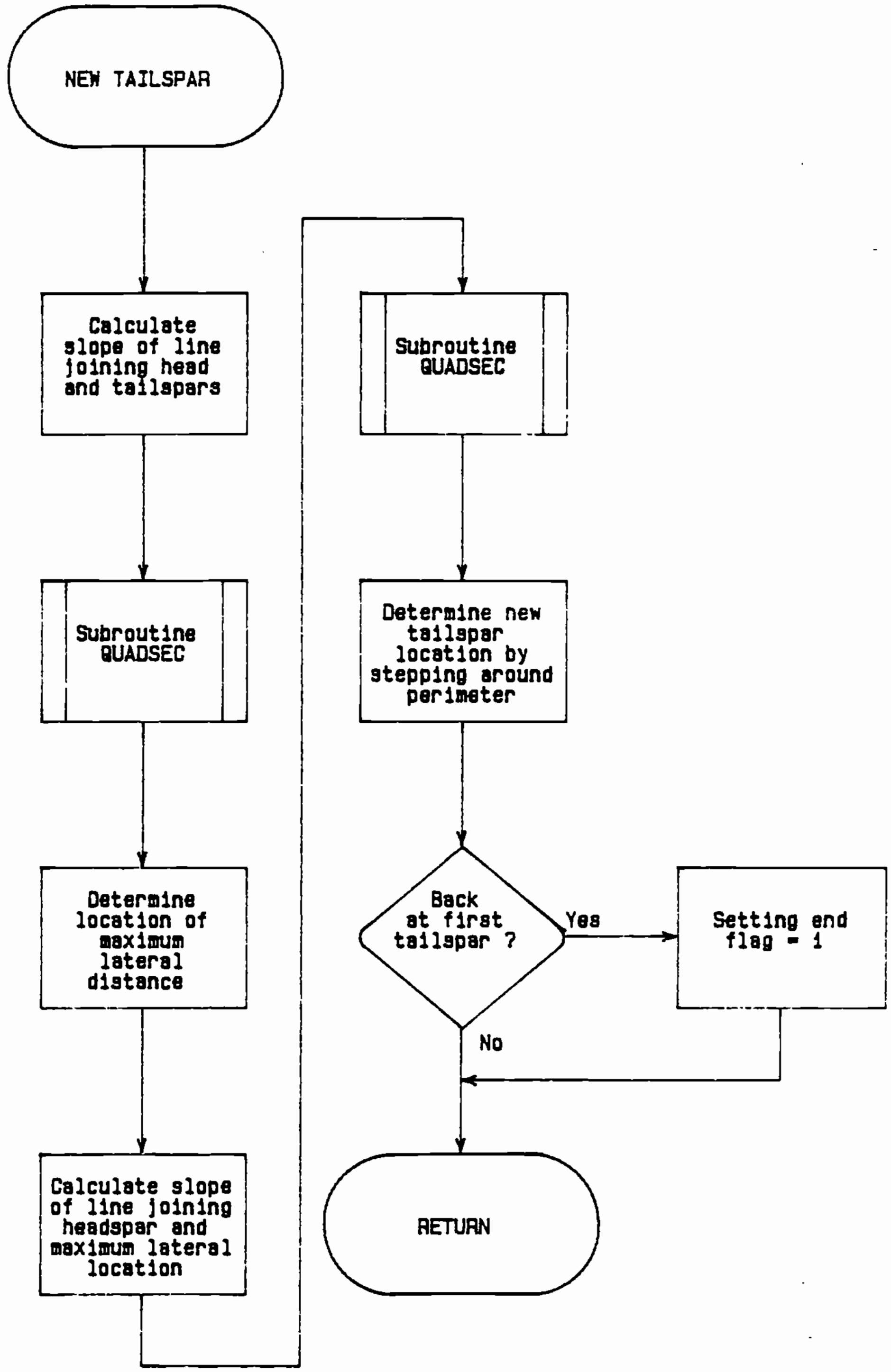

Figure B-11 Flowchart of subroutine to locate the new tailspar.

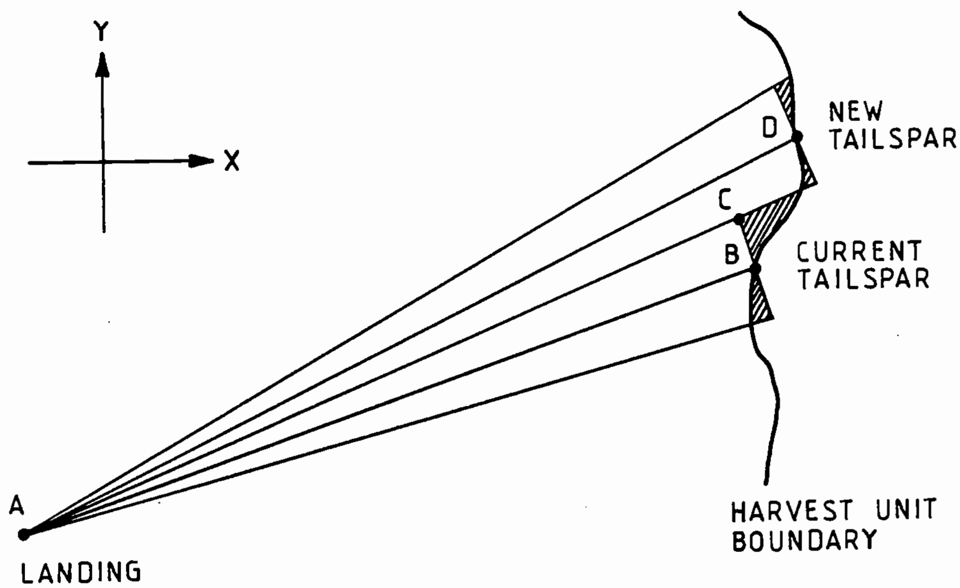

Figure B-12 Location of new tailspar.

the user having marked the location of the harvest unit boundary in a counter-clockwise direction. This requirement is noted in the on-screen user instructions in the DIGITIZE_BORDER subroutine.

The program first calculates the slope of a line, AB, joining the landing and current tailspar location (Figure B-12). Next the quadrant, in which the tailspar lies with respect to the landing, is determined. This information is needed to correctly locate the coordinates of the maximum lateral yarding distance, point C.

The program then calculates the slope of the line, AC, joining the landing and the maximum yarding distance point. The quadrant in which point C lies is determined in case it lies in a different quadrant to that of the current tailspar, point A.

Although the harvest unit boundary is shown as a continuous line on Figure B-12, in the program it is stored as a series of perimeter coordinates. The program steps, from a "marked" coordinate on the clockwise side of the current tailspar, through the perimeter coordinates until it has passed a perimeter coordinate on the counter-clockwise side of the line AC which is greater than the maximum lateral yarding distance. The new tailspar, point

D, is located between the last and second-last perimeter coordinates checked.

Figure B-12 shows that modelling the harvest unit in this way may lead to some errors since some area, included within the boundary, will be left unharvested and some area, outside the boundary, will be harvested when it was not supposed to be. These areas are shown as hatched segments. The magnitude of the error will depend on such characteristics as the ratio of the lateral yarding distance to the skyline yarding distance (the greater the ratio the greater the likely error) and the abruptness of changes in direction of the harvest unit boundary (the more erratic the boundary the greater is likely to be the error). On a practical basis it is expected that the overall error will be very small.

B.8 Terrain profile measurements

Figure B-13 shows the flowchart for the NEW_PROFILE subroutine. First the horizontal distance is calculated from the headspar on the landing to the new tailspar. This distance is then divided into 25 equally spaced zones. A figure of 25 was selected so that it would be unlikely that any of the terrain points on the harvest setting were further than 20 metres apart. At the breakpoint between

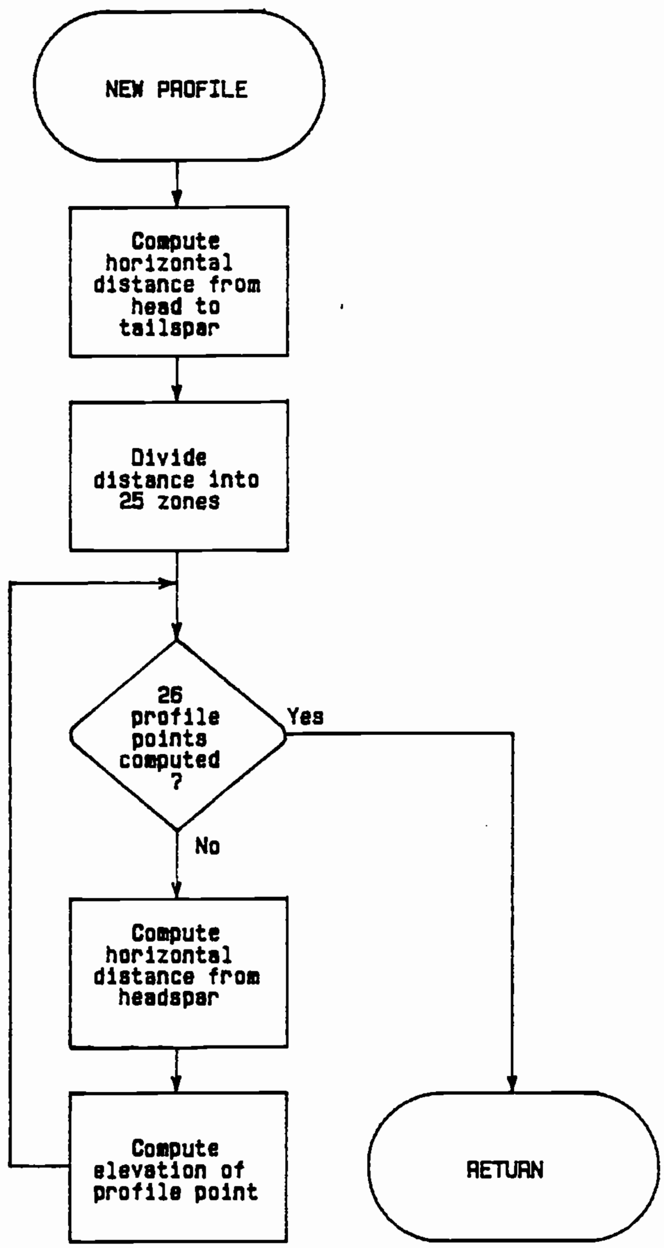

Figure B-13 Flowchart of subroutine to determine the new terrain profile.

each of these zones the program computes the horizontal distance to the headspar and the elevation of the profile point. The elevation is interpolated from the nearest available points in the DTM.

Some of the "roughness" in the actual ground profile may be reduced by the interpolation process. In an area where the terrain is very broken payloads could be over-estimated as a result of this process. For the purposes of the simulation, however, it is of minor concern.

B.9 Payload zone determination

The flowchart of the cable logging analysis [program] (CLAP) subroutine is depicted in Figure B-14. The maximum payload that can be carried, from each zone along the skyline road (or terrain profile), to the landing is determined in this subroutine. Both cable and yarder mechanics are incorporated into the analysis process.

First the log length and log-to-ground angle are set depending on whether pieces are to be extracted in a tree length or log length form. It was assumed that the average treelength piece, after felling breakage, would be 25 metres long. The average log length piece was assumed

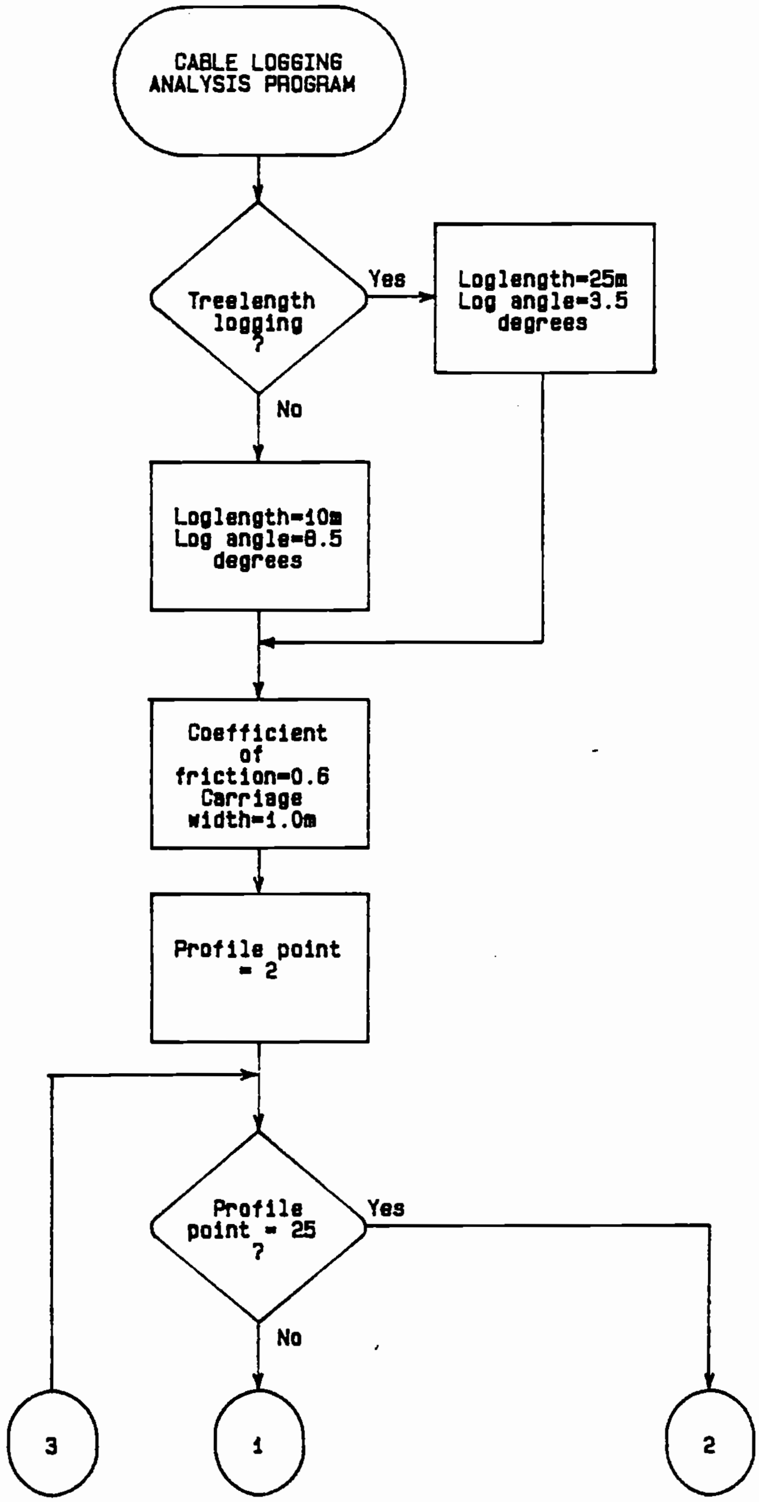

Figure B-14 Flowchart of cable logging payload analysis subroutine. (continued on following 3 pages)

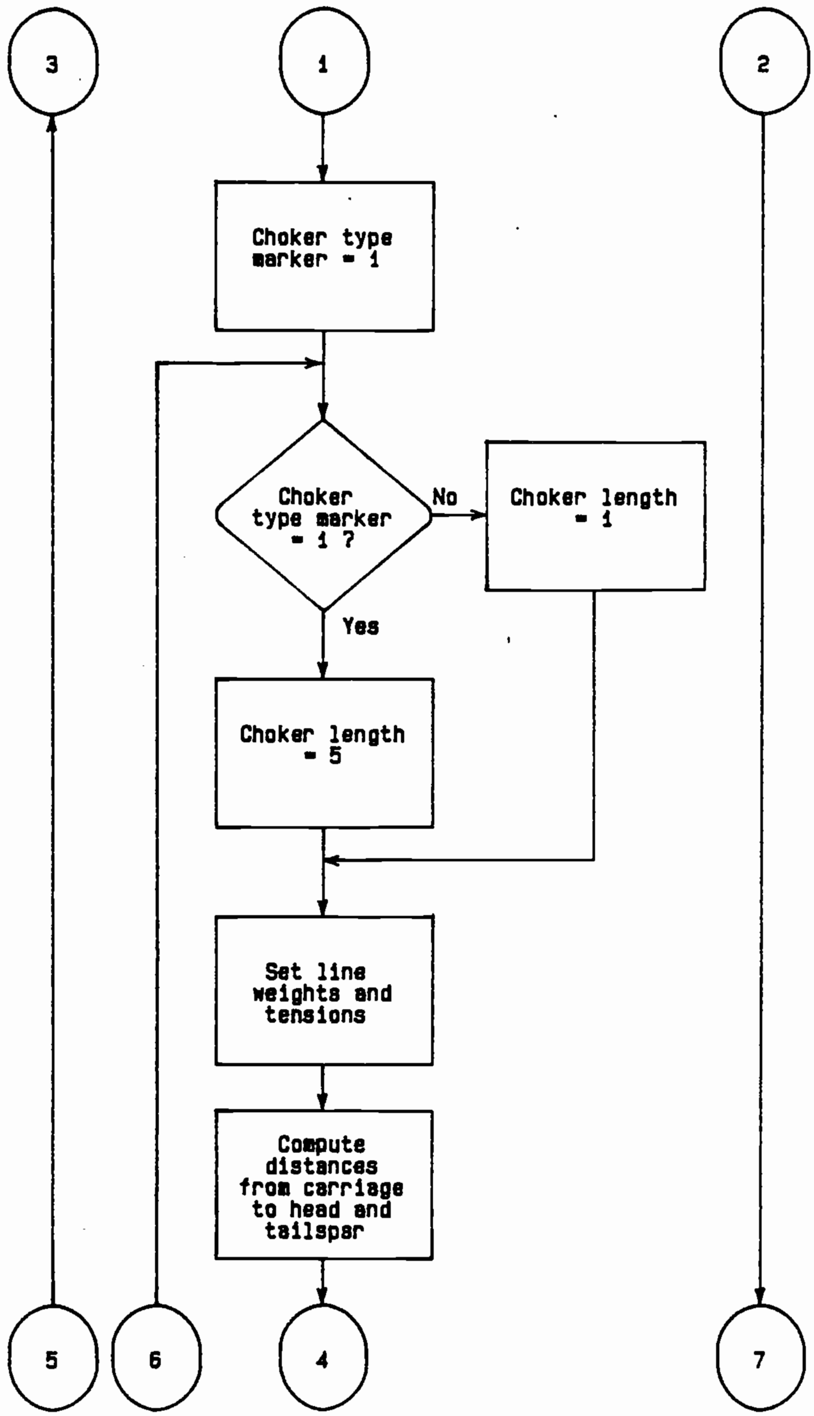

Figure B-14 Flowchart of cable logging payload analysis subroutine. (continued on following 2 pages)

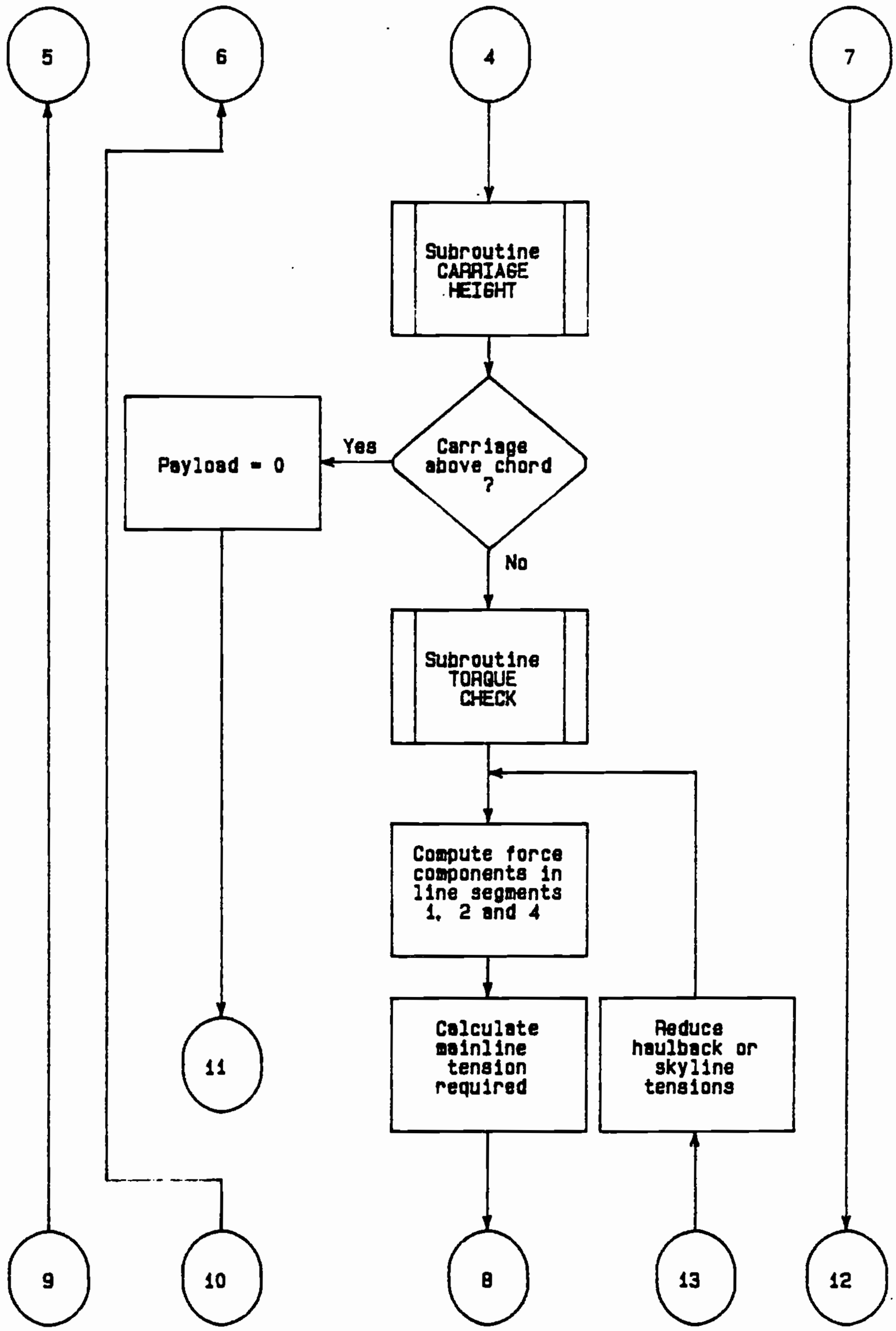

Figure B-14 Flowchart of cable logging payload analysis subroutine. (continued on following page).

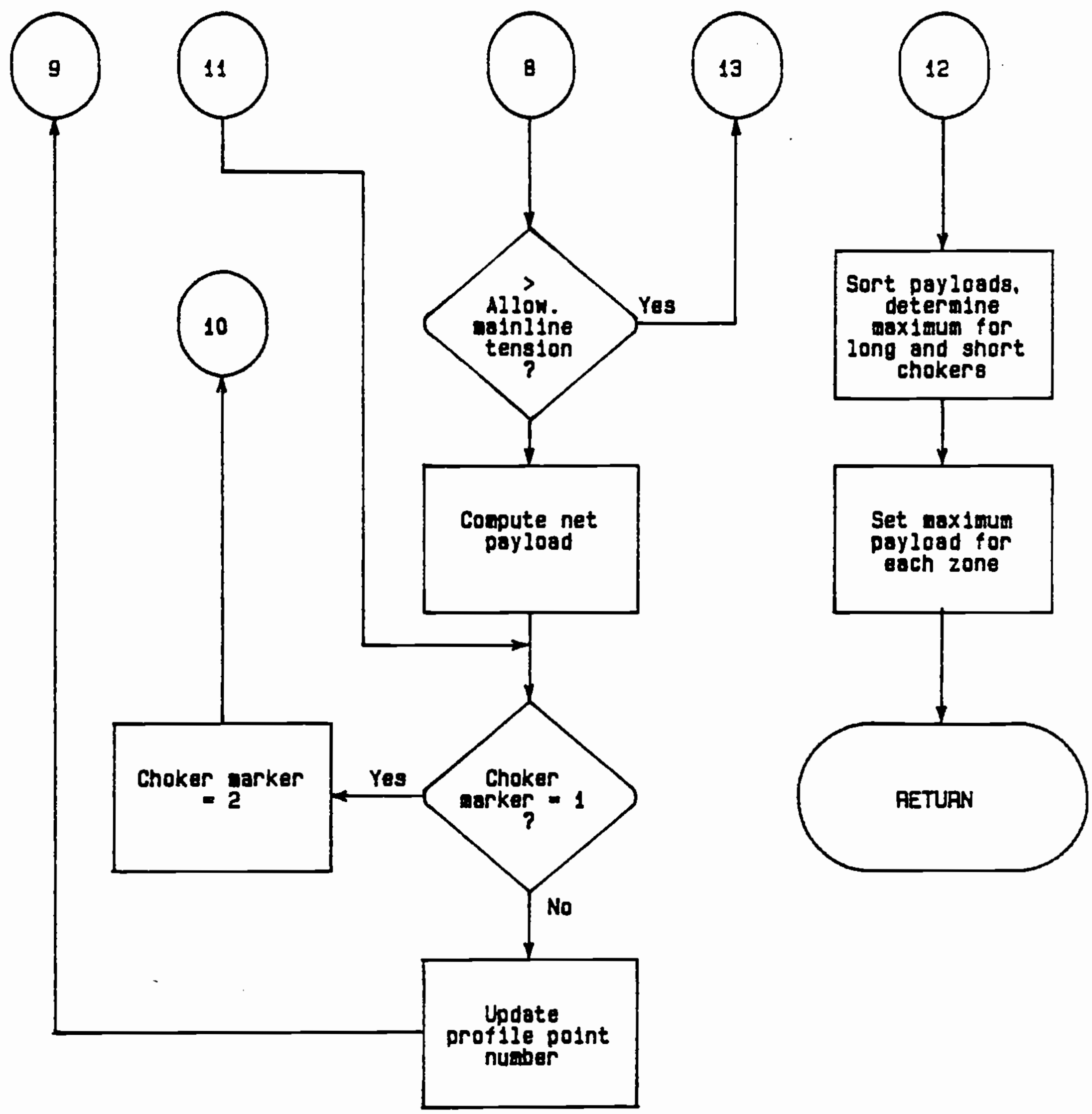

Figure B-14 Flowchart of cable logging payload analysis subroutine.

to be 10 metres long. These values are within the respective ranges for piece lengths used to develop the log size distributions used in the simulations. The log-to-ground angle, beta, (Figure B-15) was set equal to 3.5 degrees for the treelength logs and 8.5 degrees for the log length logs. These log-to-ground angles would result in a clearance under the butt end of the log of about 0.5 to 1.0 metres depending on log diameter. This was thought to be sufficient to clear most stumps. Log length and log-to-ground angle are two important parameters of log drag calculations (Falk, 1981) used in the CLAP subroutine.

The coefficient of friction between the soil and the log also determines payload capability when a log is dragging on the ground. Bennett (1962) and Garlicki and Calvert (1969) have found that this value is dependent on tree species, brush conditions, soil moisture, and soil texture among other things. Lunzman (1964) has determined that the coefficient of friction generally lies somewhere between 0.5 and 0.7. The coefficient of friction was set equal to 0.6 in this simulation model.

For all analyses the carriage width was assumed to be equal to 1 metre in depth.

It is not my intention to go into great detail on

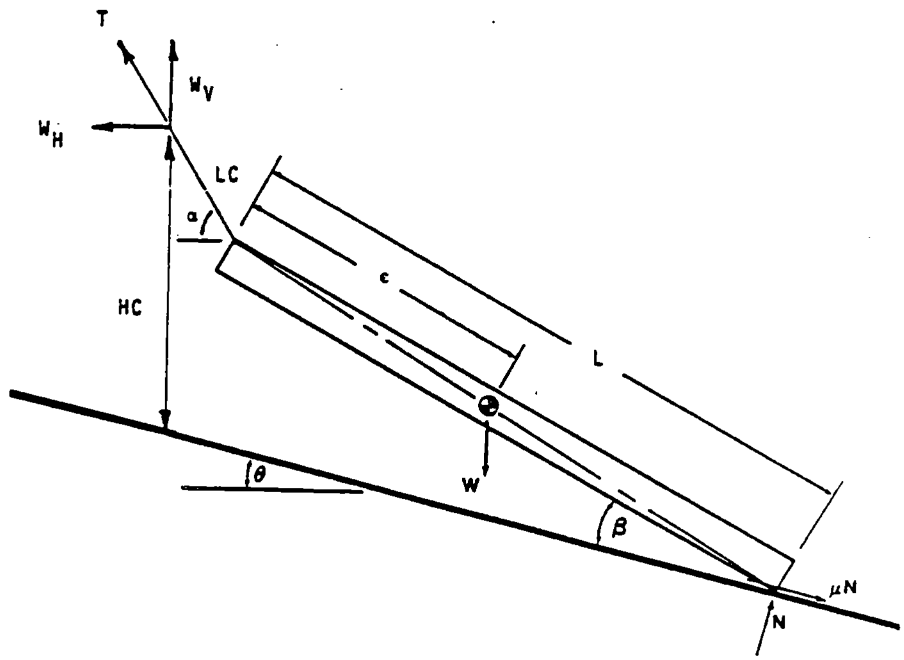

Figure B-15 Dragging log geometry.

static payload analysis in this thesis. A detailed understanding can be obtained by referring to Carson (1975 & 1977), Falk (1981), and Chung (1987). Where necessary general comments will be made however.

Payloads are calculated twice for each terrain point; once for an effective choker length of 5 metres and once for an effective choker length of 1 metre. The shorter is the choker length, the greater is the payload capability of the yarding system. Shorter chokers make it harder to reach as many logs, however. Improved payload capability under poor lift conditions during yarding simulation was the only reason for calculating payload for a 1 metre choker length. Further discussion on this point will be made in the following section.

PROSIM next sets line weights and allowable line tensions dependent on the yarding system to be used.

The horizontal distances between the carriage and the headspar and tailspar are next computed. Then a subroutine (CARRIAGE__HEIGHT) computes the ground slope, choker angle and carriage height above the ground (Figure B-15). At this stage the program checks if the carriage is above the chord (a straight line joining the top of the tower with top of the tailspar). If the carriage is above the chord the payload is set equal to zero kilograms (since cables have almost no payload capability when under compression) and the program moves on to evaluate the next terrain point.

If the carriage is below the chord PROSIM next goes to another subroutine to check if the yarder has the mechanical ability to develop tensions as large as the allowable line tensions which were based on the safe working loads of the lines. Wilbanks and Sessions (1985) and Hartsough and others (1985a & b) have shown that payload capability may be seriously overestimated if a check of the capability of the yarder is not carried out. A preliminary analysis of the machine specifications for the three yarding machines used in the simulation indicated that only the haulback tension capabilities were likely to fall below the allowable line tensions. The TORQUE___CHECK subroutine (Figure B-16) calculates the amount of haulback line out, the amount of line and the number of wraps left on the drum, and finally computes the maximum haulback tension that could be generated using the torque values shown in Table B-2. Darling and Ferguson (1985) describe the calculations required. If the maximum haulback tension that can be generated by the yarder for that terrain point is less than the allowable tension set by line safety factors then the allowable tension is

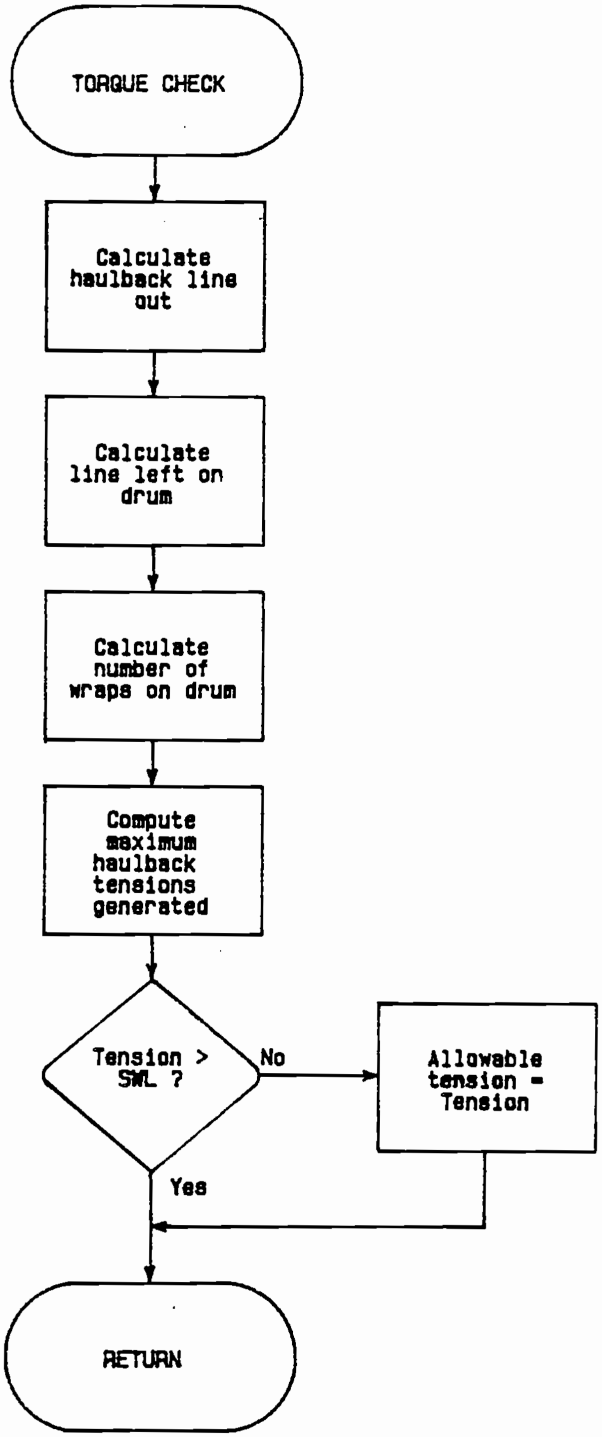

Figure B-16 Flowchart of subroutine to set maximum allowable tensions.

reduced to the torque-limited value. Otherwise the allowable tension remains unchanged.

The torque values shown in Table B-2 are the maximum braking torque assumed for the haulback drums on the Madills or the maximum torque that could be transferred across the clutch face for the Washington yarder. Yarder and system capabilities could be changed by using components which gave different values to those shown.

Table B-2 Haulback torque values used in yarders modelled

Yarder	Assumed torque value (kg.m)
Madill 009	2310
Madill 071	1085
Washington 88	3265

Once all allowable tensions have been set the program then calculates horizontal and vertical force components in line segments 1, 2, and 4 (Figure B-17). The mainline tension required to maintain static equilibrium is then computed.

If the mainline tension required is greater than the allowable mainline tension the program uses a modified

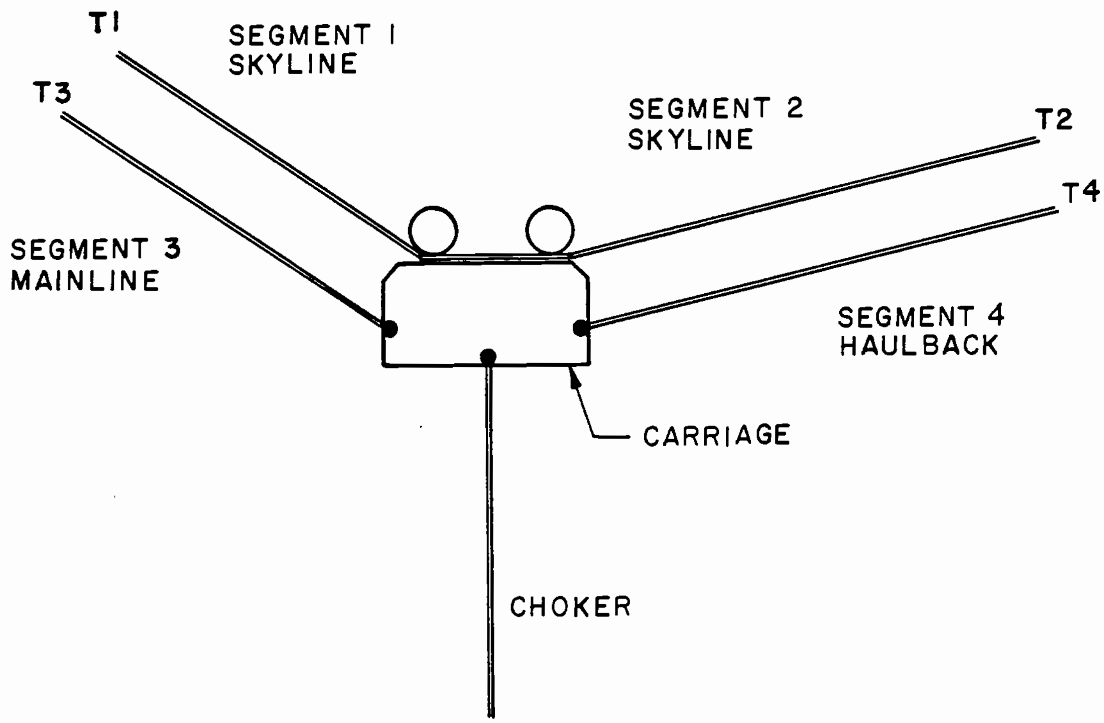

Figure B-17 Freebody diagram of carriage.

secant search routine to reduce the haulback and skyline allowable tensions. When the required mainline tension equals the allowable mainline tension the net payload for one end suspension of logs dragging along the ground is computed.

If the allowable mainline tension is not exceeded by the required mainline tension on the first set of calculations net payload is computed without a reduction in the tensions of the other lines.

When net payloads have been computed for both choker lengths for all terrain points between, but not including, the headspar and the tailspar the program then allocates maximum payload values to each of the 25 payload zones. Aulerich (1979) was one of the first to suggest the use of payload zones for cable harvest planning. The allocation procedure is the same for both the long and short chokers. First the payload for the first terrain point greater than one tower height from the yarder is set as the maximum payload for all payload zones between the terrain point and the tower. It is also set as the maximum for the payload zone immediately behind the terrain point. For the remaining payloads zones out to zone 24 a simple check is made to ensure that the maximum payload allocated to each zone is no greater than the payload capabilities of any of the terrain points a load would have to pass over on the way to the landing. The payload from the 24th zone is also allocated to the 25th zone because of the limited lift likely to be found close to the tailspar. Table B-3 gives an example of allocation of payload to the payload zones.

Table B-3 Example of payload zone determination

Terrain point	Payload capability (kg)	Payload zone	Payload used (kg)	Limiting zone
1	-	1	22560	4
2	25000	2	22560	4
3	27200	3	22560	4
4 **	22560	4	22560	4
5	19700	5	19700	5
6	20110	6	19700	5
7	18220	7	18220	7
8	15400	8	15400	8
9	13320	9	13320	9
10	11000	10	11000	10
11	8530	11	8530	11
12	9450	12	8530	11
13	10190	13	8530	11
14	9000	14	8530	11
15	9340	15	8530	11
16	7330	16	7330	16
17	6540	17	6540	17
18	7210	18	6540	17
19	8300	19	6540	17
20	8550	20	6540	17
21	7220	21	6540	17
22	6010	22	6010	22
23	5790	23	5790	23
24	3990	24	3990	24
25	-	25	3990	24

** Note: Terrain point 4 was the first terrain point more than one tower height from the yarder.

B.10 Yarding simulation

The YARDING_SIM subroutine is depicted in the flowchart in Figure B-18. It follows a similar flow in logic to the yarding simulation subprogram incorporated in the PLANS computer package. The PLANS yarding simulation subprogram was originally written and described by Gibson and others (1983). Some changes were necessary to fit the PROSIM model.

B.10.1 Log size generation and location

The YARDING_SIM subroutine first computes the area to be harvested. The area is found as the product of a triangle with base equal to the skyline road change distance and height equal to the external yarding distance. Skyline road change distances for the two Madill yarders are based on reports by Murphy (1978a & b), and for the Washington yarder on what was considered by the author to be a reasonable estimate.

The area calculation (see Figure B-12) determines the number of pieces to be extracted by the current skyline road. The subroutine then assigns a weight and location to one piece at a time until all pieces have been placed ready for extraction.

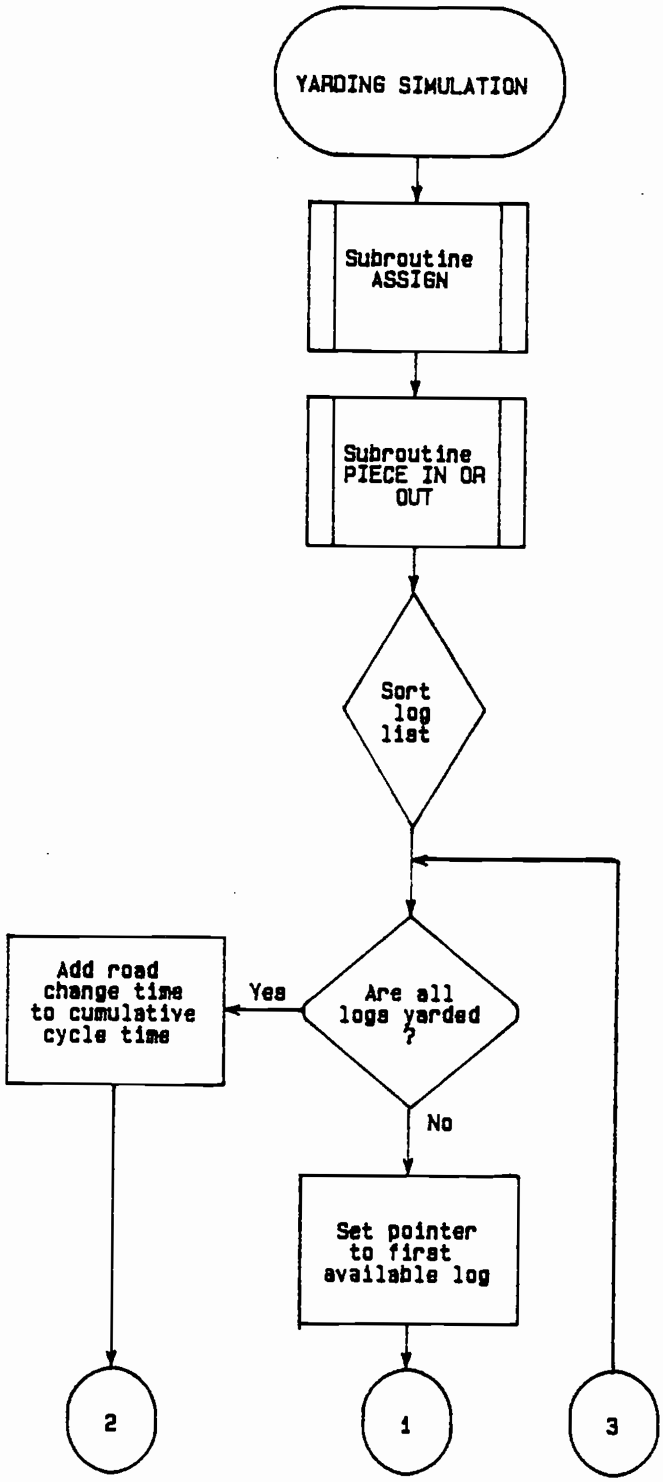

Figure B-18 Flowchart of yarding simulation subroutine. (Continued on following page)

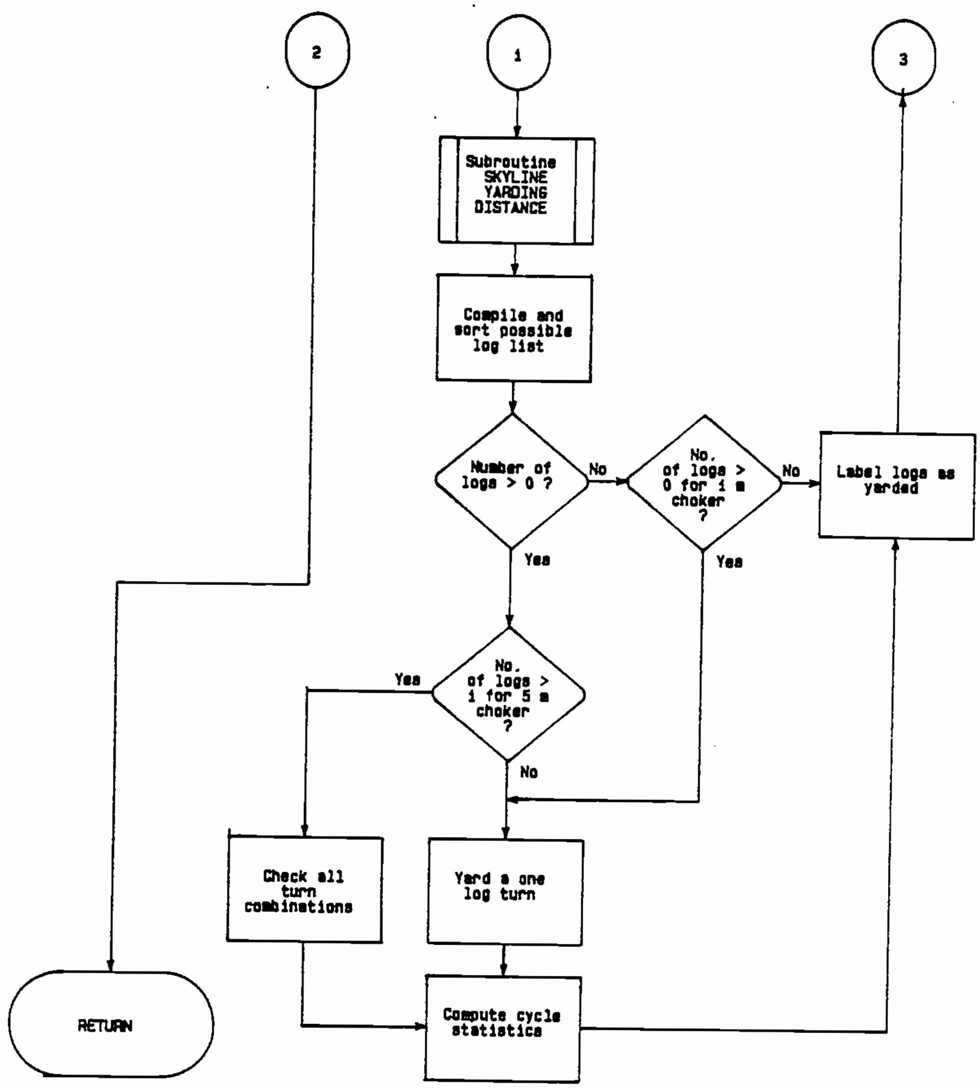

Figure B-18 Flowchart of yarding simulation subroutine.

The assignment of weight is performed by generating a weight from the Weibull log size distribution using random variates from a Uniform (0,1) distribution. A random number between 0 and 1, R, is generated and inserted in the formula below to obtain an assignable log size.

Log size = a + b*[ABS(ln(1-R))**(1/c)

where a, b and c are the distribution coefficients referred to in section B.6.

The spatial distribution of individual <u>logs</u> on a mountainous terrain setting has received little research attention. LeDoux and Butler (1981) and Gibson and others (1983) hypothesise that the spatial distribution of trees can be modelled by overlaying the area to be harvested with a grid of equally sized squares. A tree is located within each of these squares based on some measure of randomness. The location and direction of felling of each tree, and the log lengths into which each tree will be cut determine the location of individual logs. Randomness increases further. When trees are felled on mountainous terrain they usually move in a downhill direction with reference to the stump. This further complicates the location of logs with respect to standing tree location. Sessions (1979), in his yarding simulation model YARDALL, assumed that logs were distributed randomly following a Uniform (0,1) distribution in both cardinal directions. He states that the strongest argument in support of the random distribution is that YARDALL predictions of logs per turn compared favourably with field observations over the range of values investigated. Since the PROSIM model distributes individual pieces a random distribution was thought to be most applicable and was used.

Three random variates from a Uniform (0,1) distribution are required to generate a temporary location for each piece; the first generates the distance from the landing, the second generates which side of the skyline the piece will be placed, and the third generates the distance from the skyline as a function of the maximum lateral distance. The YARDING_SIM subroutine then checks whether or not the piece is within the triangle connecting the two points of maximum lateral yarding distance (at the tailspar) and the headspar on the landing. Pieces outside the triangle are ignored, pieces inside the triangle are "permanently" located. When the number of pieces permanently located equals the number of pieces to be extracted the pieces are sorted and labelled on the basis of closeness to the landing. Yarding can now begin.

B.10.2 Turn building logic

A turn building process continues until all logs have been attempted to be hooked on and yarded to the landing. The model checks to see if all logs have been yarded (or attempted to be yarded) to the landing. If not a pointer is set to the first available log and the skyline yarding distance and lateral yarding distance (perpendicular to the skyline) are computed. The payload zone in which the log lies is also computed and the allowable payload set. PROSIM uses a similar process for building a turn to the process described in detail by Gibson and others (1983). The first available log is designated the first log in the possible log list. This list will contain the first log and all logs that could be hooked to it as if building a two-log turn. Before adding logs to the possible log list a check is made to see if the difference between the allowable payload and the first log's weight is greater than the lightest log to be extracted along that skyline road. If this condition were true it would indicate that at most a single log turn could be extracted. If the single log were too large to be extracted using a 5 metre long choker the program would check if it could be yarded with the shorter choker (a long choker wrapped several times around the log until its effective length was only 1 metre). If the log could be yarded with the short choker it would be yarded as a single log turn. If it was still too big for the short choker it would be added to the total number that were too large for the whole setting and labelled so that the program would not try to add it to a later turn.

If the initial weight check of the first available log indicates that more logs can be added to the turn a list of candidate logs is compiled and sorted. The effective choker length and log location determine which logs are included in the list. Logs are added to the list until the difference between the y coordinate of the first log and the log being checked is greater than twice the effective choker length. Various combinations of logs are checked until an acceptable turn is assembled. If needed, the logic will check all combinations of N logs in the possible log list; with N being equal to the number of chokers (the maximum number of chokers that can be used in PROSIM is 6). If no satisfactory turn is found, all combinations of N-1 logs will be checked. This process is continued until a satisfactory turn is found or until the number of logs in the potential turn equals one. When checking a possible turn combination, the logic checks to see that the logs can all be hooked together by their chokers and that the combined weight of the logs does not exceed the yarding system's payload capacity.

When a satisfactory turn is found, statistics describing the turn are computed. Note that although breakage and loss of logs can occur during extraction not enough information was available in the literature to model this activity; particularly for the log-length extraction alternatives. Murphy and Hart (1979) found for tree length extraction of radiata pine that about four percent of the pieces fell off the choker and parts of eight percent of the pieces broke during extraction. The lost pieces were usually rehooked in a later turn. Breakage and loss is not incorporated into the statistics computed by PROSIM.

B.10.3 Turn statistics and cycle time determination

PROSIM accumulates running totals, and current maximum and minimum values for such parameters as number of logs per turn, turn volume, number of turns, total distance and volume yarded. It also calculates and accumulates cycle and delay times for each turn. Once all turns have been yarded for the current skyline road a skyline road change time is added to the accumulated cycle and delay times.

The yarding simulation model uses regression equations to determine the cycle and delay times for each turn. These equations are based on such parameters as skyline yarding distance, lateral yarding distance, volume yarded, number of logs hooked on, and whether pieces were extracted in tree length form to a large landing. The equations included in the model are based on production time studies carried out in radiata pine plantations in New Zealand. There is an implicit assumption, when these equations are used, that the conditions being modelled are similar to the conditions under which the data for the regression equations were collected.

The regression equations for the Madill 009 are based on production time studies by Murphy (1977, 1978b, 1983b). The logging operation was studied on several occasions under a range of operating conditions on clearfell settings. The yarder was used both as a Grabinski and highlead system. As is common practice in New Zealand tree-length logging was the norm for the operation. The logging crew were high producers and well motivated. The delay-free cycle time equation used is as follows:

$$\text{Cycle time} = 3.743 + 0.0101*\text{SYD} + 0.16*\text{LOGS} + 0.037*\text{VOL}$$

where, Cycle time is in minutes,

SYD is the skyline yarding distance along the ground measured in metres,

LOGS is the number of logs hooked on, and

VOL is the volume hooked measured in cubic metres.

During the time that the regression data was gathered the operation normally used three chokers. Since the choker setters "bonused" logs wherever possible, that is hooked more than one log in a single choker, up to seven logs arrived at the landing. PROSIM assumes that up to six chokers are being used but only one log can be hooked onto each choker.

The cycle delay time equation used is as follows:

Delay time = 0.925 + 1.301*LOC - 0.00263*LOC*SYD

where, Delay time is in minutes,

SYD is the skyline yarding distance measure in metres, and

LOC is a 0,1 indicator variable for log manufacturing location; LOC = 1 if logs were manufactured on a landing, or 0 otherwise.

Fisher and Peters (1982) have stated that actual delay time depends on individual operating conditions and the skill of the yarding crew. They generalise, however, that delay for most cable operations can be estimated as about 20% of the cycle time. For the conditions under which the study data was gathered the percentage delay time was calculated to be about 25%.

The skyline road change study was also carried out on the same Madill 009 (Murphy, 1978b). A mean time of 30 minutes per road change was found where no "mobile anchor" attached to a crawler tractor was used.

The regression equations for the Madill 071 are also based on a production time study by Murphy (1978c). This is the only study available on the Madill 071 under operating conditions similar in steep country plantations in New Zealand. The Madill 071 logging crew were not as skilled as the crew operating the Madill 009. This will make it difficult to compare production rates for different machines. Since the intention of the simulation model was primarily to compare log manufacturing systems rather than machines the differences between the crews should cause few problems. The Madill 071 was studied during the tree-length extraction of a clearfell setting.

The delay-free cycle time equation is as follows:

Cycle time = 3.516 + 0.008*SYD + 0.238*LOGS + 0.052*VOL

where, Cycle time is in minutes,

SYD is the skyline yarding distance along the ground measured in metres,

LOGS is the number of logs hooked on, and

VOL is the volume hooked measured in cubic metres.

Three chokers were usually used by this logging crew also. The maximum number of pieces yarded to the landing was 6 due to bonusing of logs.

The cycle delay time equation used in the model for this operation was as follows:

Delay time = 2.46 + 0.14*LOC

where, Delay time is in minutes, and

LOC is a 0,1 indicator variable for log manufacturing location; LOC = 1 if logs were manufactured on a landing, or 0 otherwise.

Delay time for this operation, expressed as a percentage of cycle time, is quite high at about 45%.

The skyline road change time for this operation was calculated to be about 75 minutes. Although this is considerably higher than for the Madill 009 operation it is representative for slackline systems as reported by Van Winkle (1977).

A preliminary, unpublished production time study of a Washington 88 has been carried out in New Zealand. The study is not available for general distribution. Only elemental times were reported in the study. Personal discussions with one of the researchers involved with the study permitted me to crudely derive the following delay-free cycle time equation:

$$\text{Cycle time} = 1.204 + 0.0054*SYD + 0.483*LOGS + 0.0125*VOL + 0.032*LYD$$

where, Cycle time is in minutes,

SYD is the skyline yarding distance along the ground measured in metres,

LOGS is the number of logs hooked on,

VOL is the volume hooked measured in cubic metres, and

LYD is the lateral yarding distance normal to the skyline measured in metres.

During the time the study was carried out the tree-length and log-length logs were pulled from underneath the tower to a secondary landing for further processing. The delay time equation was adjusted to represent conditions where processing may also have been carried out on the primary landing. The cycle delay time equation used in the model was as follows:

Delay time = 0.378 + 0.14*LOC

where, Delay time is in minutes, and
LOC is a 0,1 indicator variable for log manufacturing location; LOC = 1 if logs were manufactured on a landing, or 0 otherwise.

The delay time for this operation expressed as a percentage of the cycle time was about 16%.

The logging crew normally used three chokers and pulled slack up to 15 metres either side of the skyline. A maximum distance between skyline roads of 30 metres was in the PROSIM model. The mean road change time for this operation was found to be about 35 minutes, similar to that for the Madill 009 operation.

B.11 Yarding production summary

Figure B-19 depicts the flowchart for the SUMMARY subroutine. This subroutine summarises yarding statistics for the setting which may be of interest to a logging planner.

The total number of days to harvest the setting is computed in the following manner:

Days to harvest setting = M + C/E

where: M = the time to move-in and move-out of the harvest unit. In PROSIM this was set as 0.75 days. This value is based on a report by Blundell and Cossens (1985).

C = the cumulative time for yarding the setting as determined in the YARDING_SIM subroutine. As stated in section B.10 the cumulative time includes all cycle times, road changes, and production delays.

E = the effective day length. It is calculated by subtracting from the scheduled time on site such times as legal rest breaks, repair and maintenance time, warm-up and shut down at the end of the day, personal delays, shifting equipment around on the landing, talking to supervisors and so on. Murphy (1977 & 1978c)

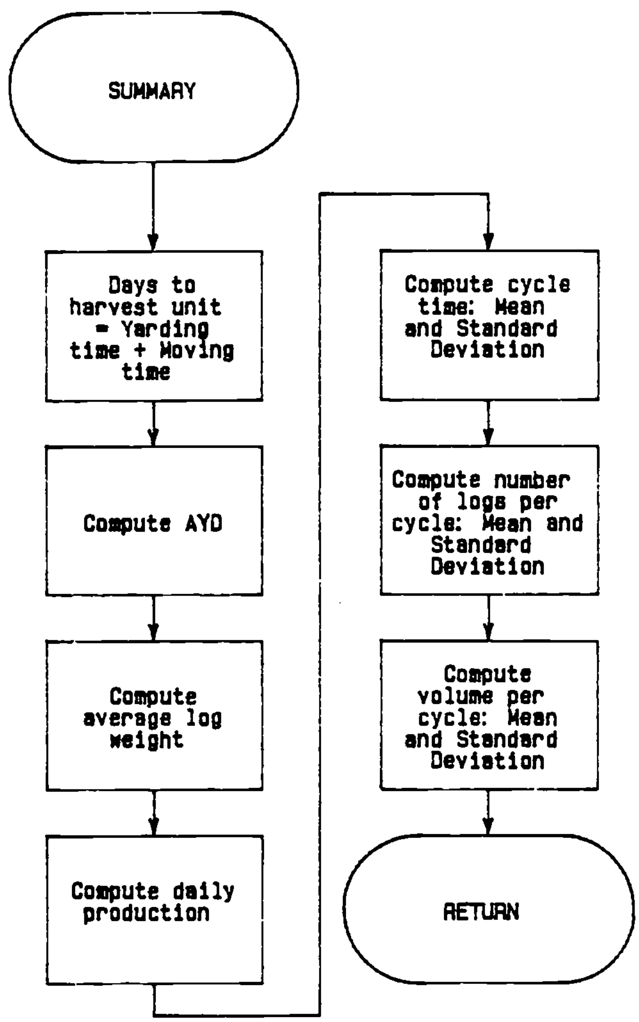

Figure B-19 Flowchart of yarding production summary subroutine.

has estimated that the effective day length for large and medium yarders in New Zealand is 395 and 375 minutes, respectively.

The average yarding distance for the setting is next computed by dividing the total yarding distance by the number of turns.

The average log weight is computed by dividing the total weight yarded by the total number of logs yarded.

The average daily production is calculated by dividing the total volume yarded by the number of days to harvest the setting.

The subroutine then calculates an estimate of the mean and standard deviation for following cycle parameters:

- delay free cycle time
- number of logs hooked per cycle
- volume extracted per cycle.

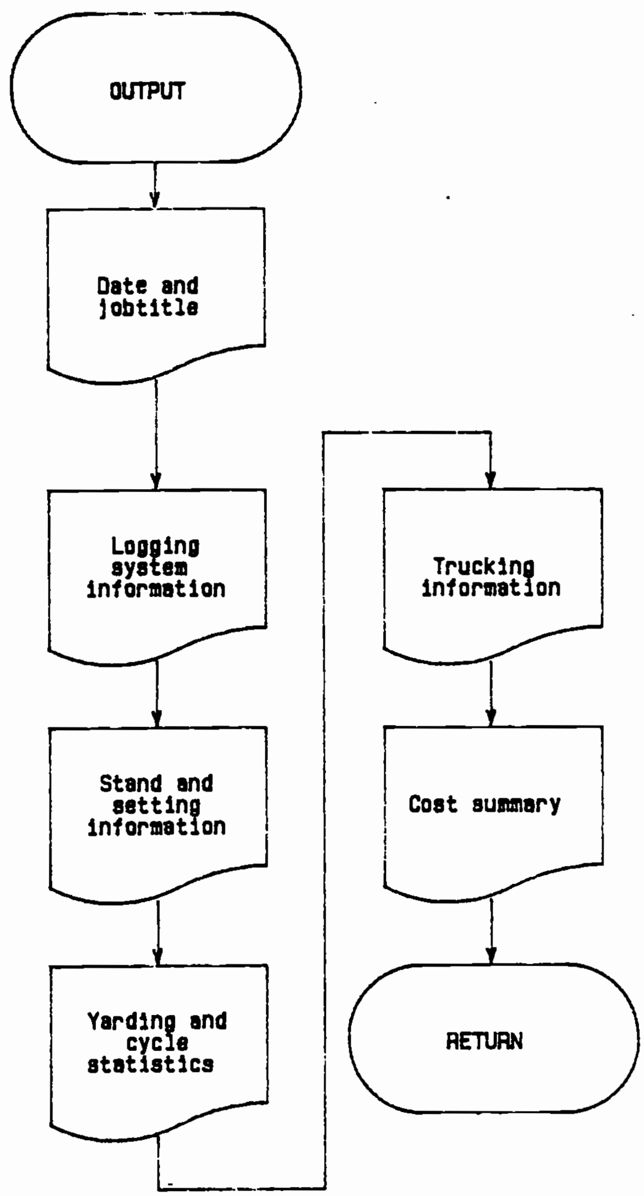

Figure B-20 Flowchart of output reporting subroutine.

B.12 Output

A flowchart of the OUTPUT subroutine is shown in Figure B-20. The reader should also look at Figure 5-8 to see the format of the output. Logging system information, stand and setting information, yarding and cycle statistics, trucking information and a cost summary are provided in the output.

APPENDIX C. Central processing yard costs.

The costs contained in this appendix are derived from a publication by Sinclair and Wellburn (1984) entitled "A handbook for designing, building, and operating a log sortyard". Much less final log manufacturing and handling is carried out at a central sortyard than at a central processing yard. The machinery and manpower configuration had to be increased, over levels indicated by Sinclair and Wellburn, for a given volume passing through the yard. The increases were based on field observation of loaders and log manufacturers working on large landings in New Zealand.

The central processing yard was assumed to be a permanent fixture with a 10 year depreciable life. Sinclair and Wellburn, in their costing of this type of yard, assume that the main working surface of the yard is asphalted. Asphalting is one of the major capital costs. Hampton (1981) has suggested that the cost of asphalting is more than offset by reduced repairs and maintenance on the loading equipment, reduced degrade to the product of the yard (logs), reduced enviromental problems (e.g. dust), and increased loader and manpower productivity. The cost of asphalting was also included in this analysis.

Machinery related costs in Sinclair and Wellburn's publication were updated and indexed to known New Zealand equipment costs. They can only be classed as indicative. It was assumed that the central processing yard would have an annual throughput of about 250,000 cubic metres per year. The average number of pieces handled per year was estimated to be about 500,000. The area required for processing and sorting this number of pieces would be about 4 hectares. An additional 8 hectares was allocated for future expansion and other activities, such as storage, debris disposal, buildings, and fire-pond. Only 4 of the total 12 hectares would be asphalted.

Costing

Fixed costs:

Land purchase	12 ha @ $2,000/ha	$ 24,000
Site preparation	12 ha @ $32,000/ha	$ 384,000
Lighting		$ 100,000
Buildings		$ 100,000
Truck scales		$ 80,000
Debris burner		$ 20,000
Sorting and dumping bunks		$ 45,000
Asphalt paving	4 ha @ $220,000/ha	$ 880,000
Other (add 5% to current total)		$ 80,000
Total fixed costs		$1,713,000

<u>Variable costs:</u>

Loaders	- Annual ownership - for 2 Cat. 980's	$ 340,000
	- for 4 Cat. 966's	$ 460,000
	Repairs and Maintenance	$ 375,000
Services		$ 10,000
Debris disposal @ $0.15/cu.m.		$ 34,000
Asphalt resurfacing		$ 20,000
Gravel resurfacing		$ 24,000
Labour	- processors 5 men	$ 117,000
	- loader operators 6 men	$ 140,000
	- weighmaster	$ 21,000
	- manager	$ 31,000
Return on investment (5%)		$ 86,000
Depreciation (10 years, 10% resale)		$ 154,000
Total annual variable costs		$1,812,000

Unit cost = (Annual variable costs)/(Annual throughput)

= $1,812,000/250,000

= $7.25 per cubic metre.

APPENDIX D. Summary tables for PROSIM simulation runs

Yarder = Madill 009 Harvest unit area = USA1

Parameter	Bucking Pattern					
	TREE	AVIS	SOLLY	S,D&J	FIXED	BUTT
Recovery (% of tot. vol.)	97.4	99.0	98.9	99.1	98.3	98.7
Yarder prod. (cu. m./day)	228	157	172	176	193	202
Av. yarding dist. (m.)	210	198	198	198	199	201
Cycle volume (cubic metres)						
- mean	5.68	3.43	3.77	3.86	4.27	4.48
- std. dev.	2.95	1.48	1.86	1.79	2.36	2.38
- min.	0.24	0.05	0.03	0.05	0.02	0.14
- max.	17.78	8.53	12.87	11.72	15.12	14.03
Number of logs (per cycle)						
- mean	1.83	4.55	4.12	4.14	3.42	2.91
- std. dev.	0.86	1.55	1.59	1.59	1.52	1.40
- min.	1	1	1	1	1	1
- max.	6	6	6	6	6	6
Cycle time (minutes)						
- mean	6.37	6.60	6.54	6.54	6.46	6.40
- std. dev.	0.96	1.06	1.06	1.06	1.05	1.04
- min.	4.04	3.97	3.92	3.93	3.99	4.00
- max.	8.06	8.58	8.54	8.59	8.49	8.40
Total system cost ($/cu.m.)	29.67	38.16	35.72	34.94	42.30	41.28

APPENDIX D .cont. Summary tables for simulation runs

Yarder = Madill 009 Harvest unit area = USA2

Parameter	Bucking Pattern					
	TREE	AVIS	SOLLY	S,D&J	FIXED	BUTT
Recovery (% of tot. vol.)	94.4	97.2	97.2	97.2	96.7	96.8
Yarder prod. (cu. m./day)	228	146	161	164	186	197
Av. yarding dist. (m.)	250	241	239	239	240	238
Cycle volume (cubic metres)						
- mean	6.13	3.42	3.80	3.87	4.43	4.74
- std. dev.	3.26	1.49	1.93	1.85	2.56	2.62
- min.	0.31	0.06	0.02	0.06	0.04	0.12
- max.	20.57	8.51	11.74	10.84	17.37	16.92
Number of logs (per cycle)						
- mean	1.98	4.57	4.16	4.17	3.52	3.07
- std. dev.	0.93	1.56	1.61	1.59	1.54	1.46
- min.	1	1	1	1	1	1
- max.	6	6	6	6	6	6
Cycle time (minutes)						
- mean	6.81	7.03	6.96	6.97	6.89	6.81
- std. dev.	1.38	1.50	1.50	1.49	1.49	1.51
- min.	4.02	3.93	3.93	3.94	3.94	3.95
- max.	9.58	9.75	9.75	9.80	9.84	9.84
Total system cost ($/cu.m.)	30.71	40.89	37.77	37.21	43.55	42.20

APPENDIX D. cont. Summary tables for simulation runs

Yarder = Madill 009   Harvest unit area = NZ1

Parameter	Bucking Pattern					
	TREE	AVIS	SOLLY	S,D&J	FIXED	BUTT
Recovery (% of tot. vol.)	96.8	98.6	98.5	98.6	98.2	98.1
Yarder prod. (cu. m./day)	219	152	167	169	188	198
Av. yarding dist. (m.)	217	208	208	210	210	212
Cycle volume (cubic metres)						
- mean	5.51	3.38	3.75	3.78	4.22	4.49
- std. dev.	2.70	1.50	1.85	1.78	2.37	2.36
- min.	0.15	0.03	0.02	0.06	0.01	0.13
- max.	17.60	8.88	12.25	11.72	13.91	13.36
Number of logs (per cycle)						
- mean	1.78	4.49	4.10	4.06	3.39	2.92
- std. dev.	0.83	1.59	1.59	1.60	1.50	1.39
- min.	1	1	1	1	1	1
- max.	5	6	6	6	6	6
Cycle time (minutes)						
- mean	6.43	6.68	6.63	6.65	6.55	6.52
- std. dev.	1.09	1.19	1.19	1.19	1.18	1.18
- min.	4.01	3.92	3.92	3.93	3.98	3.99
- max.	8.70	9.07	9.12	9.08	8.98	8.98
Total system cost ($/cu.m.)	30.84	39.33	36.55	36.25	43.05	41.88

APPENDIX D. cont. Summary tables for simulation runs

Yarder = Madill 009 Harvest unit area = NZ2

Parameter	Bucking Pattern					
	TREE	AVIS	SOLLY	S,D&J	FIXED	BUTT
Recovery (% of tot. vol.)	97.3	99.1	98.7	98.7	98.5	98.6
Yarder prod. (cu. m./day)	206	152	168	170	190	198
Av. yarding dist. (m.)	218	207	206	206	208	210
Cycle volume (cubic metres)						
- mean	5.21	3.44	3.84	3.86	4.36	4.59
- std. dev.	2.25	1.49	1.86	1.82	2.27	2.26
- min.	0.24	0.04	0.02	0.06	0.03	0.07
- max.	16.43	8.89	12.25	11.33	13.62	12.99
Number of logs (per cycle)						
- mean	1.68	4.58	4.18	4.14	3.45	2.97
- std. dev.	0.73	1.54	1.58	1.60	1.50	1.35
- min.	1	1	1	1	1	1
- max.	4	6	6	6	6	6
Cycle time (minutes)						
- mean	6.41	6.69	6.63	6.63	6.55	6.50
- std. dev.	1.14	1.24	1.26	1.26	1.25	1.23
- min.	4.01	3.97	3.94	3.95	3.93	3.99
- max.	8.82	9.51	9.49	9.46	9.51	9.43
Total system cost ($/cu.m.)	33.38	39.71	36.77	36.42	43.16	42.18

APPENDIX D. cont. Summary tables for simulation runs

Yarder = Madill 071 Harvest unit area = USA1

Parameter	Bucking Pattern					
	TREE	AVIS	SOLLY	S,D&J	FIXED	BUTT
Recovery (% of tot. vol.)	96.5	99.5	99.4	99.2	99.2	99.0
Yarder prod. (cu. m./day)	168	119	129	132	144	151
Av. yarding dist. (m.)	207	199	197	197	198	200
Cycle volume (cubic metres)						
- mean	5.25	3.50	3.84	3.90	4.32	4.59
- std. dev.	2.25	1.49	1.83	1.78	2.22	2.28
- min.	0.15	0.04	0.02	0.05	0.02	0.13
- max.	13.28	9.07	10.77	10.69	12.22	13.84
Number of logs (per cycle)						
- mean	1.69	4.64	4.18	4.18	3.46	3.14
- std. dev.	0.75	1.55	1.60	1.61	1.52	1.39
- min.	1	1	1	1	1	1
- max.	5	6	6	6	6	6
Cycle time (minutes)						
- mean	5.84	6.39	6.28	6.29	6.15	6.06
- std. dev.	0.78	0.95	0.95	0.95	0.94	0.92
- min.	3.88	3.78	3.78	3.84	3.81	3.80
- max.	7.73	8.13	8.15	8.16	8.17	8.14
Total system cost ($/cu.m.)	32.28	41.46	38.78	38.24	45.25	44.13

APPENDIX D. cont. Summary tables for simulation runs

Yarder = Madill 009 Harvest unit area = USA2

Parameter	Bucking Pattern					
	TREE	AVIS	SOLLY	S,D&J	FIXED	BUTT
Recovery (% of tot. vol.)	91.5	95.9	95.4	95.8	95.1	95.0
Yarder prod. (cu. m./day)	161	111	121	123	137	141
Av. yarding dist. (m.)	255	244	243	243	244	244
Cycle volume (cubic metres)						
- mean	5.56	3.47	3.83	3.90	4.42	4.60
- std. dev.	2.59	1.49	1.90	1.83	2.37	2.41
- min.	0.15	0.01	0.01	0.06	0.04	0.07
- max.	17.23	9.81	11.61	11.53	11.87	12.48
Number of logs (per cycle)						
- mean	1.80	4.63	4.21	4.20	3.52	2.99
- std. dev.	0.83	1.55	1.63	1.62	1.54	1.43
- min.	1	1	1	1	1	1
- max.	6	6	6	6	6	6
Cycle time (minutes)						
- mean	6.27	6.75	6.66	6.66	6.53	6.41
- std. dev.	1.13	1.29	1.30	1.30	1.28	1.27
- min.	3.82	3.80	3.81	3.79	3.83	3.80
- max.	9.04	9.02	9.11	9.10	9.19	9.23
Total system cost ($/cu.m.)	34.28	44.25	41.30	40.69	47.08	46.24

APPENDIX D. cont. Summary tables for simulation runs

Yarder = Madill 071 Harvest unit area = NZ2

Parameter	Bucking Pattern					
	TREE	AVIS	SOLLY	S,D&J	FIXED	BUTT
Recovery (% of tot. vol.)	82.2	97.9	97.4	97.5	96.6	97.2
Yarder prod. (cu. m./day)	118	88	94	93	103	102
Av. yarding dist. (m.)	217	222	221	222	221	222
Cycle volume (cubic metres)						
- mean	3.56	2.47	2.60	2.57	2.86	2.82
- std. dev.	1.47	1.01	1.13	1.07	1.26	1.26
- min.	0.15	0.08	0.02	0.06	0.04	0.12
- max.	13.62	8.28	10.77	8.72	11.54	12.47
Number of logs (per cycle)						
- mean	1.23	3.30	2.85	2.76	2.28	1.83
- std. dev.	0.45	1.40	1.30	1.24	1.07	0.84
- min.	1	1	1	1	1	1
- max.	3	6	6	6	6	4
Cycle time (minutes)						
- mean	5.72	6.20	6.10	6.08	5.96	5.92
- std. dev.	0.87	0.94	0.93	0.92	0.91	0.91
- min.	3.85	3.79	3.80	3.81	3.81	3.82
- max.	7.85	8.82	8.84	8.77	8.76	9.33
Total system cost ($/cu.m.)	44.02	53.09	50.73	50.91	56.63	55.57