EFFECT OF YARDING OPERATIONS
ON LOG RECOVERY VALUE

by

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This thesis deals with the problem of controlling losses in log recovery value in yarding operations. It is believed that losses under current operating methods can be substantial over time. The objective is to find ways of applying statistical quality control methods to controlling and reducing these losses.

A literature review was done to determine the statistical techniques available. A pilot study was done concurrently to determine the current levels of value loss and test methods of measuring value loss. The final step was to recommend a procedure for monitoring and controlling log value losses based on the findings of the literature review and the pilot study.

Value loss estimates in the pilot study were consistent with losses discussed in the literature (1-2%). The problems encountered with the methods used in the pilot study, however, were believed to be severe enough to limit the usefulness of the methods and the results. The methods were found to be cumbersome and time consuming as well as needing considerable refinement in the area of scaling and grading for true value recognition.

The recommended statistical quality control method can be used operationally without the necessity of immediate improvement of scaling and grading techniques. The method involves observing occurrences of log damage and recording detailed information related to those occurrences so that the causes of the damage can be determined. Procedures can then be developed to correct these causes. The method relies on the use of statistical control
charts for attributes for monitoring log damage and highlighting periods of abnormal results for further investigation.
# TABLE OF CONTENTS

**ABSTRACT**

**TABLE OF CONTENTS**

**LIST OF TABLES**

**LIST OF FIGURES**

**ACKNOWLEDGMENT**

**INTRODUCTION**

1

**CHAPTER ONE - LOG RECOVERY VALUE**

2

Potential gains:

3

Objectives:

5

**CHAPTER TWO - LITERATURE REVIEW**

6

Quality control concepts:

7

Developing a quality control system:

9

**CHAPTER THREE - PILOT STUDY**

34

Methods:

35

Results:

42

Analysis of Damage:

48

**CHAPTER FOUR - RECOMMENDED QUALITY CONTROL METHOD:**

58

Operational quality control procedures:

58

Long term application of control charts:

64

Analyzing the system:

66

**CHAPTER FIVE - DISCUSSION**:

67
Literature review: 67
Pilot study: 68
Recommended quality control system: 69
Conclusions: 70

BIBLIOGRAPHY 73

APPENDIX - MAPS 75
LIST OF TABLES

Table 1. Sample data and control limit calculations for X-bar chart for variables. 12

Table 2. Sample data and control limit calculations for attributes chart with variable sample size. 23

Table 3. Site characteristics. 36

Table 4. Yarding system characteristics. 37

Table 5. Sample statistics. 39

Table 6. Loss in recovery value by system. 43

Table 7. Yarding results and statistics by period. 45
LIST OF FIGURES

Figure 1. Shewhart X-Bar chart for variables. 11

Figure 2. Operating characteristic curves for varying sample sizes. 19

Figure 3. Shewhart chart for attributes. 22

Figure 4. Checksheet for damage type (partial). 29

Figure 5. Checksheet for damage causes and conditions (partial). 30

Figure 6. Control chart for log damage (study data). 46

Figure 7. Stabilized control chart for log damage. 47

Figure 8. Histogram of damage by type. 49

Figure 9. Pareto chart of damage by type. 49

Figure 10. Checksheet for yarding damage assessment. 59

Figure 11. Control chart for yarding damage. 63
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INTRODUCTION

Losses in log value due to yarding damage can have a significant effect on the profitability of a harvesting operation. Estimates of the amount of value lost in the literature are in the order of 2 percent of the total value of the logs produced. This can amount to millions of dollars for some larger harvesting operations. The first step in reducing this type of loss is to determine the causes of the damage. Measures to reduce damage can then be developed based on widely used statistical quality control techniques.

This thesis is concerned with finding ways to reduce log damage associated with the yarding methods commonly used on the coast of British Columbia. To begin the process of gathering data necessary for development of improved methods, a pilot study was done. This is discussed in detail in the methods section. A literature review was carried out to determine the state of current technology and find out what methods are being used in other locations to control harvesting operations. The knowledge gained in the pilot study and the literature review was applied in the development of a comprehensive method of controlling value loss in yarding operations. The details of this method are provided in Chapter 4.
CHAPTER ONE - LOG RECOVERY VALUE

Log recovery value is the value of the standing tree which is recovered through logs delivered to the end user, either a converting mill or the open market. It reflects the value of the products which can be produced from the logs and excludes the waste or unusable portion of the tree. In a sawmill, one of the prime objectives is to recover the highest total value from the raw material, and similarly, all phases of harvesting operations should be concerned with recovering the highest value from the standing tree.

Little attention has been paid in the past to evaluating the effects of yarding operations on the value of the logs recovered. Cost (per unit volume) has been the main criteria for measuring performance and planning yarding operations.

This emphasis on costs ignores the fact that profitability is a function of both cost and value, as shown by the profit equation (Murphy and Twaddle, 1985):

\[
\text{Profit} = \text{Volume} \times (\text{Unit Value} - \text{Unit Cost})
\]

Losses can occur when inappropriate yarding methods are used, or are used incorrectly, causing log damage and reducing log value. Damage to logs means breakage at any point and or slabbing or splitting of the butt or top. It also includes other types of damage such as bark removal, crushing of the wood fibres by chokers and penetration or ripping of the wood fibres by a
mechanical grapple. Gabrielsson et al (1989) mention the above types of damage, among others, as causing a reduction in the value of a sawlog. By reducing any of these types of log damage or breakage, log recovery value can be increased.

**Potential gains:**

The potential gains to be achieved through controlling losses are dependent on the amount of the loss in recovery value presently occurring, and how much the losses can be reduced. Losses in recovery value during the yarding process have been estimated by several researchers. These estimates can provide a guide to how much value is being lost in a particular system, but the amount of loss reduction that can be achieved cannot realistically be estimated without in-depth knowledge of a particular system:

- Williston (1979), in estimating the total dollar opportunity that is available through improved practices in the woods in the Pacific Northwest, stated that 3.5% of the merchantable stem of small trees was lost during primary transport and at the landing.

- McIntosh (1968) studied losses at various stages of the harvesting process in the interior of British Columbia and found that breakage during skidding averaged 1.7% of the net log scale. McIntosh believes that optimal performance would result from adequate supervision and natural pride of the woods crew in "good" operations.

- Murphy and Twaddle (1985) summarized studies done in New Zealand in which value losses from extraction and butt
damage were found to be 1 to 2 percent of potential value. It was suggested that statistical quality control techniques be applied to reducing these losses.

No studies were found which applied to the type of site and stand conditions existing in the remaining old growth stands on the coast of British Columbia. Harvesting of old growth stands in this area is done under some of the most difficult operating conditions anywhere in the world. Steep slopes, rocky terrain, high rainfall, and extremely varied tree size and age combine to increase the chance of log damage during yarding. Therefore, it is reasonable to expect that value losses under these conditions would be in the order of 2% or even more.

Extending the above estimate, it is possible to project the potential dollar loss for a setting, or an entire harvest operation. Based on a setting size of 15 hectares, a volume per hectare of 1000 m$^3$ and an average value of $60 per m$^3$, a value loss of 2.0 percent would result in a total loss of $18,000 for a single setting, or $1.20 per m$^3$. For a typical woods operation producing 500,000 m$^3$ per year, this would be equivalent to a loss of $600,000 in one year. A small reduction in the percentage of this value loss could have a considerable effect on the profitability of an operation.
Objectives:

The objective of this thesis is to develop a quality control method using control charts to reduce damage to logs in yarding operations under coastal British Columbia operating conditions.

The first part of this thesis is a review of standard methods of quality control as discussed in the literature. This included a review of concepts in the field of statistical process control relevant to the control of yarding operations. The review provided a description of practical methods for controlling quality in yarding operations from which a detailed procedure can be developed.

The second part was a pilot study to develop and test the procedures available for gathering various types of data on yarding operations. The experience gained in the pilot study was applied to the refinement of a practical method of quality control which can be tested in further field studies. The results of the pilot study included a review of the problems encountered and how they affected the choice of the proposed quality control methods. The results also included estimates of average value loss developed to meet the specific objectives of the study.
CHAPTER TWO - LITERATURE REVIEW

The first step in developing a quality control system for yarding operations is a review of the current technology and selection of the appropriate statistical control methods. This includes a review of the types of control charts which could be used and planning the steps necessary for their application.

Many books have been written on quality control techniques using statistical methods, including texts by Juran and Gryna (1993), Grant and Leavenworth (1988) and Duncan (1965). These texts were reviewed in part, as well as other publications including research by Gitlow (1987) and Scherkenbach (1986), which outlined the application of current developments in the field to specific quality control problems. Other sources of information on quality control were lectures and course notes by Maness (1993), the Quality Control Handbook edited by Juran (1962 edition), the joint LIRO/FIEA Seminar: Quality issues in harvesting and processing; and the IUFRO P.3.07-01 Harvesting and product quality inaugural meeting; both held in New Zealand in 1993.

Murphy and Twaddle (1985), discuss the use of quality control charts to monitor a log making operation at a landing. Stuart, Grace, and LeBel (1993), describe several examples of applications in forest operations where various types of charts including histograms, Pareto charts and Shewhart charts have been used to monitor production processes and assist in controlling
variability. The relevant concepts described in these sources are discussed in the following sections.

**Quality control concepts:**

Quality control is often thought to mean the detection of defective products of a manufacturing process. This is commonly known as Acceptance Sampling, where the objective is to determine whether to accept or reject a particular lot or product based on inspection of the parts making up that lot. In fact, quality control is much more than acceptance sampling. Statistical methods initially developed by Shewhart in 1924 have made it possible to change the emphasis to managing and controlling production processes with the objective of preventing defective goods from being produced (Duncan, 1965). The current approach to quality control has two basic aspects:

- Ensuring that all goods produced meet the requirements of the appropriate specification. This is done by monitoring each stage of the production process so that deviations from normal operating behaviour are detected and corrected as they occur.

- Continuous improvement of the methods of production so that the quality of goods produced is constantly increased. This is achieved by analysis of the production system and continued strengthening of areas where quality levels are lowest.

The basis for effective quality control methods is the appropriate use of statistics. An understanding of basic
statistical concepts, including the concept of variability, is needed in order to effectively implement quality control methods.

In any manufacturing process, there will be some differences in quality between individual units produced, no matter how accurate or well controlled the process. Variation is the amount by which the quality of an individual unit will differ from other units as indicated by the measurement of a specific variable or attribute. Variability is the range of values over which the individual measurements occur. Variability is usually defined statistically by the standard deviation (σ). In common manufacturing situations, when the system is operating in a normal, consistent manner, 99.73%, or nearly all of the individual measurements, should be within three standard deviations (±3σ) of the mean of the individual measurements for a total variation of six times standard deviation, assuming that the measurements are normally distributed. This is commonly known as the "six-sigma (6σ) rule" (Maness, 1993). Variability is dependent on the physical factors which affect a process. Duncan (1965) discusses two types of variation: chance variation and special variation.

Chance or common variation is the sum of the effects of the whole complex of chance causes. These variations occur at random and follow the laws of statistics. Little can be done about chance variation except to revise the process. On the other hand, there is variation caused by special or assignable causes. Assignable causes are non random events resulting from changes in the
factors which affect the operating characteristics of the process.

These types of factors include (Duncan, 1965):

- Differences among machines.
- Differences among workers.
- Differences among materials.
- Differences in each of the above over time.
- Differences in their relationship to one another.

Variation in quality between individual units can be reduced and controlled, but it cannot be eliminated. It is a natural aspect of any dynamic system. Management actions to control variation should be based on the cost/benefit relationship of those efforts. It may be relatively inexpensive to reduce variation produced by assignable causes, but as variation becomes more and more due to chance causes, the cost of reducing variation will increase until it eventually exceeds the increase in value achieved. At this point, reappraisal and application of different techniques may be required to further improve quality.

**Developing a quality control system:**

The successful development of a quality control system depends on how well the causes of variation in a system or process are understood. A system or process is a combination of activities operating in a coordinated manner to accomplish a defined goal or objective. In the process of yarding logs, this means the combination of people, materials, equipment, methods, and
environment which produces the desired result: logs delivered to the landing undamaged. Detailed study of the system is required to determine its specific operating characteristics.

The implementation of quality control methods in a yarding operation has two distinct phases; eliminating special causes of variation and continuous improvement:

**Phase I: Eliminating special causes of variation:**

Eliminating special causes of variation begins with monitoring the process which is to be controlled using statistical charts over an extended period of time. The aspect of time is important as it allows short term fluctuations to be compared to long term trends. This comparison will disclose whether short term fluctuations represent a change in the operating characteristics of the system which should be investigated or only natural variation in the system which should be allowed to continue as long as the specifications are being met. It is important to note that in this phase the objective is to reduce the variability of the system, that is to reduce the variance of individual measurements from the mean. Reductions in the mean level of breakage are the subject of Phase II discussed below.

**System monitoring:**

The most common method of monitoring a system is using control charts, of the type known as Shewhart charts. There are two main types of Shewhart charts; charts for monitoring variables and
charts for monitoring attributes. Both types are similar in appearance, differing only in what type of data is plotted.

**Charts for variables:**

The main types of charts for variables are X-Bar and R charts. They should be used when some measurable quantity is being monitored such as the amount of value lost in yarding. X-Bar charts are discussed below to demonstrate how control charts for variables are prepared.

Figure 1 is a typical X-Bar chart prepared using hypothetical data from a series of samples of logs where the percent value lost for each log has been determined by estimating the value of each log before and after yarding.

Figure 1. Shewhart X-Bar chart for variables.

![Figure 1. Shewhart X-Bar chart for variables.](image)

After Murphy and Twaddle (1985).
In Figure 1, the Y-axis shows the range of the variable being measured (value loss percent). The X-axis shows the sample number and follows the chronological order in which the samples were taken. The calculations of the control limits are discussed below.

Table 1. Sample data and control limit calculations for X-bar chart for variables.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value loss (%)</td>
<td>2</td>
<td>8</td>
<td>3</td>
<td>12</td>
<td>18</td>
<td>9</td>
<td>11</td>
<td>24</td>
<td>9</td>
<td>14</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Mean value loss (%)</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9.4</td>
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<tr>
<td>Centre line</td>
<td>9.4</td>
<td>9.4</td>
<td>9.4</td>
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<td>9.4</td>
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<tr>
<td>Upper control limit</td>
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<td>20.2</td>
<td>20.2</td>
<td>20.2</td>
<td>20.2</td>
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<tr>
<td>Lower control limit</td>
<td>0.0</td>
<td>0.0</td>
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<td>0.0</td>
<td>0.0</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Standard Deviation Based on long term sample averages:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.6</td>
</tr>
<tr>
<td>3 * Std. Deviation</td>
<td>10.8</td>
<td>10.8</td>
<td>10.8</td>
<td>10.8</td>
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<td>10.8</td>
<td>10.8</td>
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</tr>
</tbody>
</table>

In the X-Bar chart, the mean of each sample is plotted and compared to the grand sample mean, which is plotted as the centre line. The grand sample mean is derived from previous observations, if these are available. The upper and lower control limits are set so that if the system is under control, nearly all of the sample means will fall between the limits. Initially, this is the mean or centre line plus or minus three
times the standard deviation of the mean, based on previous observations of the population. The total range between upper and lower control limits is therefore six times the standard deviation based on measurements of individual items in the population. If the calculated value of the lower control limit is less than zero, the limit is set at zero. The data should be tested to ensure that it is normally distributed before using this method.

The standard deviation used in the calculation of control limits can be derived in several ways; either by analyzing the data from the current sample, from previous data, or set by management to meet certain objectives (Duncan, 1965). If sufficient historical data is available, the standard deviation of individual items sampled can be calculated as shown in Equation 1 (Duncan, 1965).

\[
s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n - 1}} \quad \text{Equation 1}
\]

Where:
- \(s\) = standard deviation of the sample,
- \(x_i\) = the \(i\)th value of \(x\)
- \(\bar{x}\) = the mean value of the sample, and
- \(n\) = the number of items in the sample.

If past data is not available from which to determine the standard deviation, current sample data can be used. In this case the range, the difference between the highest and the lowest value in each subgroup, is calculated, and the average range, \(\bar{R}\), is calculated for all subgroups in the current data. It is
not appropriate to calculate the standard deviation with Equation 1, above, using the current data, because the estimate will not be an independent measure for detecting extreme variations in the means (Duncan, 1965). Conversion factors are taken from standard statistical tables. The calculation of the standard deviation when ranges are used is shown by Equation 2 (Duncan, 1965).

\[
    s = \frac{\bar{R}}{d_2}
\]

Equation 2

Where:

- \(d_2\) = tabulated value for \(n\) sample size, and
- \(\bar{R}\) = mean of sample ranges

(Ref.: Duncan, 1965; Table D1, p 908).

When samples are taken in groups such as 4 or 5 at a time, as is usually done with variables charts, and the averages of the groups (\(\bar{X}\)) plotted on the control chart, the standard deviation obtained above must be corrected for the effect of using sample averages instead of individual measurements. The effect, as described by the Central Limit Theorem, is that the distribution of the means (\(\bar{X}\)) tends to be normal even though the individual measurements are not and the variability of the means is decreased as sample size increases (Grant and Leavenworth, 1988). Therefore the standard deviation of the population must be adjusted by dividing by the square root of the sample size, to be usable for control charts in which sample averages are plotted instead of individual measurements. This adjustment is shown by Equation 3 (Oakland and Followell, 1990).
\[ S_{\bar{x}} = \frac{s}{\sqrt{n}} \]

Where:

\( S_{\bar{x}} \) = Standard deviation of the sample means.

Guidelines exist for choosing the number of samples to be taken. Oakland and Followell (1990), suggest that as a rule of thumb for control charts for variables, at least 100 individual measurements should be taken over a period of time. Duncan (1965) suggests that sample sizes of 4 or 5 are close to optimum for detecting large shifts in the process average, such as a shift of 2 times the standard deviation or more. If shifts as small as one standard deviation are to be detected, sample sizes of 15 to 20 are more effective. The individual measurements can therefore be taken in 20 groups of 5 and the results averaged for each group. If the sample size is revised, the control limits should be recalculated as well. Samples should be taken from homogeneous populations whenever possible; smaller sample sizes will make it easier to achieve this (Duncan, 1965).

Whether the individual measurements or sample means are used to estimate the population standard deviation, the estimated values should be considered preliminary only and used with caution, until enough time has passed to develop long term averages.

To use charts for variables, the results of successive measurements are plotted and the resulting patterns analyzed. A point outside the control limits indicates that a change has occurred in the average value of the output from the system, but
nonrandom behaviour of points within the control limits can also indicate that a special cause of variation has occurred. The various patterns and their interpretation are discussed in more detail under attribute charts, below.

Charts for attributes:

When it is not possible or practical to measure a variable directly, control charts for attributes can be used (Maness, 1993). These charts can be used when a yes or no question can be answered concerning a specific attribute, such as whether a log is damaged or not. The attribute to be controlled should be easily recognizable. The same analysis of trends can be applied to this type of chart as used for variables charts.

Sample sizes for attribute charts are usually larger than for variables charts because the proportion of the population having the attribute in question is usually very low, often as low as 1 percent.

There are a number of ways of choosing the sample size and the frequency of sampling. According to Duncan (1965), the methods suggested in the literature are guidelines only. A complete solution to the problem of determining sample sizes and frequency of sampling requires knowledge of the costs involved in not catching shifts in performance when they occur, costs connected with amount and frequency of sampling and the probabilities of shifts occurring.
The most important consideration in choosing the sample size, according to Duncan (1965), is determining the rational subgroup. It is important that the samples represent homogeneous units such as the output from a particular shift or machine. Mixing samples from several shifts or machines can make it very difficult to find reasons for variation. Therefore, although a fixed sample size can be used, it is more effective to do a complete inspection of the output from a specific shift or machine on a regular basis.

Calculating sample size requires a knowledge of the amount of variation which it is desired to detect. This is because sample size and sensitivity of the chart are directly related to each other. Increasing sample size increases sensitivity and vice versa. A preliminary estimate of the expected variation can be obtained by taking samples of the process output until a relatively stable average is obtained. Juran (1962) suggests that the minimum sample size can be calculated based on the preliminary process average using Equation 4:

\[
    n = \frac{9 - 9\overline{p}}{\overline{p}} \tag{Equation 4}
\]

Where:
\[
    \overline{p} = \text{average fraction defective, and}
\]
\[
    n = \text{the minimum sample size.}
\]

No estimate of sensitivity is required for Juran's equation, because it is based on an implied sensitivity of 3 times the standard deviation. As this amount of variation is commonly used
to set control limits in control charts, Juran's method can be used in many circumstances. For example, if the process average is 0.02, (2%), the calculated sample size using this equation is 441 items.

Another method suggested by Duncan (1965) is dependent on the shift desired to be detected and the proportion defective in the population as shown by Equation 5. This method determines the sample size required to have a 50% chance of catching an increase in the average, with a single sample (Duncan, 1965).

\[
d = 3 \sqrt{\frac{p(1-p)}{n}} \tag{Equation 5}
\]

Where:
- \(d\) = shift in average to be detected, and
- \(p\) = fraction defective in population.

For example, if the shift to be detected \((d)\), was set at three times the standard deviation, the estimated sample size for a population with an estimated process average of 2%, would be 445 items, very similar to the estimate provided by Juran's equation. Closer examination will reveal that Duncan's equation can be resolved into Juran's equation when the desired sensitivity is equal to \(p\).

The relationship between sample size and sensitivity of the sample is best shown with what is known as an Operating Characteristic (OC) curve. OC curves are used in many areas where statistics are applied, for example in designing samples
for acceptance sampling. An OC curve for an attribute chart shows the probability of a single sample falling within the control limits when the process fraction defective is currently above or below the mean or centre line on the chart. The curve shows the risk of saying the process is in control at the mean level if a sample point falls within the limits when the process is actually operating at a different level. That is, the curve shows the chance of not catching a shift in the process average in the first sample taken after the shift occurs (Duncan, 1965). Figure 2 shows a series of OC curves for a control chart with an upper limit only. Charts for attributes will frequently have no lower control limit, usually when the process fraction defective is very small or when it is not considered important for control purposes.

Figure 2. Operating characteristic curves for varying sample sizes.
In this example, the long term average process fraction defective is estimated to be 0.019 (1.9%), a value corresponding to the average log breakage experienced during the pilot study. The sample sizes range from 100 to 800 items and the upper control limits are 0.060, 0.048, 0.039, and 0.033 respectively, reflecting the increased precision of the sample with increasing sample size. Items in a yarding operation would be individual logs yarded. Each curve in Figure 2 is based on the same average process fraction defective, and shows the effect of changing sample size on the probability of not catching a shift at various levels of current process fraction defective. For example, if the current process fraction defective increased to 0.06, there would be a 0% chance of failing to detect the shift with a sample size of 800 items. The probability of failing to detect the shift increases to 45% as sample size decreases to 100 items. If 95% probability of detecting a shift to this level, (0.06), was desired, the sample size would be approximately 400 items, using 1-\( p_a \) to estimate the probability of catching a shift. 1-\( p_a \) is known as the "Power of the Test" (Maness, 1993).

The above example shows the relationship between sample size and the ability to detect changes in the process average. Because of the difficulty of obtaining consistent sample sizes in logging where conditions are extremely variable and production can change rapidly from one time period to the next, the best approach is to base sample size on the optimum subgroup for maximum sampling efficiency and use OC curves to determine the reliability of the actual samples that result.
Sample size affects the spread of the control limits, because the standard deviation which is used to calculate the control limits is dependent on sample size. Therefore, if sample sizes vary significantly, i.e. by more than 25%, separate upper and lower control limits should be calculated for each sample point using the individual sample sizes (Maness, 1993). The mean probability as calculated from all of the samples should still be used for each calculation. The calculation of control limits for attribute charts is based on the assumption that when the fraction defective in the population is low; 10% or less, the population being sampled follows the binomial distribution (Maness, 1993). When the fraction defective is higher, the normal distribution can be assumed (Duncan, 1965). For most applications to yarding operations, the binomial distribution would be used, because the number of logs damaged should not exceed 10% of the total logs yarded. Equation 6 can be used for calculating the standard deviation of samples taken from a population with a binomial distribution. The value of p to be used in this formula is the process fraction defective (Duncan, 1965).

\[ s = \sqrt{\frac{p(1-p)}{n}} \]  \hspace{1cm} \text{Equation 6}

Where:

\( s \) = standard deviation of the sample means.

When setting up a chart initially, the assumption is made that the process is in control. The average fraction defective for
the first group of samples is then used as an estimate of the process fraction defective (Duncan, 1965).

Figure 3 gives an example of a Shewhart chart for attributes with a variable sample size, using hypothetical data such as might be obtained from observations of logs damaged during yarding. Table 2 shows the sample data used for Figure 3 and the method of calculation of the control limits.

Figure 3. Shewhart chart for attributes.

In Figure 3, upper and lower control limits move closer together as sample size increases, reflecting the increased confidence in the estimate of the mean, and farther apart as sample size decreases.
Table 2. Sample data and control limit calculations for attributes chart with variable sample size.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size</td>
<td>550</td>
<td>249</td>
<td>301</td>
<td>400</td>
<td>275</td>
<td>255</td>
<td>600</td>
<td>175</td>
<td>244</td>
<td>255</td>
<td>350</td>
<td>277</td>
</tr>
<tr>
<td>Damaged</td>
<td>8</td>
<td>3</td>
<td>8</td>
<td>17</td>
<td>5</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>6</td>
<td>13</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Proportion</td>
<td>0.014</td>
<td>0.012</td>
<td>0.027</td>
<td>0.042</td>
<td>0.018</td>
<td>0.008</td>
<td>0</td>
<td>0.017</td>
<td>0.025</td>
<td>0.051</td>
<td>0.017</td>
<td>0.018</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>proportion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.019</td>
</tr>
<tr>
<td>Centre line (Mean)</td>
<td>0.019</td>
<td>0.019</td>
<td>0.019</td>
<td>0.019</td>
<td>0.019</td>
<td>0.019</td>
<td>0.019</td>
<td>0.019</td>
<td>0.019</td>
<td>0.019</td>
<td>0.019</td>
<td>0.019</td>
</tr>
<tr>
<td>Upper control limit.</td>
<td>0.037</td>
<td>0.046</td>
<td>0.043</td>
<td>0.040</td>
<td>0.044</td>
<td>0.045</td>
<td>0.036</td>
<td>0.051</td>
<td>0.046</td>
<td>0.045</td>
<td>0.041</td>
<td>0.044</td>
</tr>
<tr>
<td>Lower control limit</td>
<td>0.002</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.003</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>constant</td>
<td>0.413</td>
<td>0.413</td>
<td>0.413</td>
<td>0.413</td>
<td>0.413</td>
<td>0.413</td>
<td>0.413</td>
<td>0.413</td>
<td>0.413</td>
<td>0.413</td>
<td>0.413</td>
<td>0.413</td>
</tr>
<tr>
<td>root of n</td>
<td>23.45</td>
<td>15.78</td>
<td>17.35</td>
<td>20.00</td>
<td>16.58</td>
<td>15.97</td>
<td>24.49</td>
<td>13.23</td>
<td>15.62</td>
<td>15.97</td>
<td>18.71</td>
<td>16.64</td>
</tr>
<tr>
<td>3*Std. Deviation</td>
<td>0.018</td>
<td>0.026</td>
<td>0.024</td>
<td>0.021</td>
<td>0.025</td>
<td>0.026</td>
<td>0.017</td>
<td>0.031</td>
<td>0.026</td>
<td>0.026</td>
<td>0.022</td>
<td>0.025</td>
</tr>
</tbody>
</table>

Initially the control limits are placed at the center line or mean plus or minus three times the standard deviation which gives a total range of six standard deviations. After some experience is gained, the control limits may be adjusted to suit the objectives of management. Warning limits can be used concurrently with control limits to indicate a need to collect more data to check on the possibility of the process being out of control. Warning limits may be set at one or two times the standard deviation (1σ or 2σ limits). Ideally the limits should be set at a level such that exceeding that level indicates that a predetermined course of action should be taken, and therefore
should be set at a critical value for that action. Setting the level too low will result in unnecessary problem solving activity, whereas, if the level is too high, actual problems may not be detected. As discussed above, control limits are lowered as sample size increases. Holding the control limits at the same level while increasing the sample size, has the effect of making the OC curve steeper, thereby increasing the sensitivity or ability of the chart to detect shifts.

As for setting sample size and frequency, setting the level of control limits requires balancing the cost of investigating problem situations with the cost of ignoring problems which go undetected. A detailed analysis of costs should be made, which is beyond the scope of this thesis.

Criteria for judging out of control situations are given by several authors. These criteria can be used for any type of chart. According to Duncan (1965) they are:

- One or more points outside the control limits.
- One or more points in the vicinity of a warning limit.
- A run of 7 or more points up or down or above or below the control limit. This will indicate a problem emerging or a sustained shift in the process average.
- Cycles or other nonrandom patterns in the data. Experienced operators may be able to relate patterns to changes in operating conditions.
- A run of 2 or 3 points outside of 2σ limits.
- A run of 4 or 5 points outside of 1σ limits.
The above criteria are based on the premise that if no points fall outside the control limits and if there is no evidence of nonrandom variation in the points within the limits such as a run, there is not enough evidence to assume that special causes of variation are acting on the process (Duncan, 1965). The criteria for the number of points in a run is based on the probability of getting a run of that number in a sample taken from a population of a given size. For example there is a 5 percent chance of getting a run of 7 or more in a population of 20 (Hansen, 1963). Duncan (1965) cautions that using multiple criteria increases the risk of looking for trouble when none exists.

**Target for reduction of log damage:**

There is no accepted standard or target level in the industry for damage during yarding operations. When beginning a control program the target should be zero breakage. Once a monitoring process has been set up, long term averages for particular sets of site, stand and equipment parameters will be developed. Review of these averages will give some indication as to the level of breakage to be expected under current conditions. However, for maximum effectiveness of the control chart method, the target should remain at zero, particularly during the second phase, continuous improvement.
Choosing the type of chart:

Experience in previous studies has shown that the original volume of broken logs or the grade of the broken section is difficult to determine in yarding operations unless detailed measurements of logs have been made prior to yarding, because of difficulties in finding the broken piece or pieces (McNeel, 1993). The resultant value loss cannot be accurately determined without this information. Making detailed measurements prior to yarding may not be practical under operating conditions because of the large number of logs which would have to be measured in order to ensure a representative number of damaged logs is included in the results. Control, however, can still be achieved by observing and recording qualitative attributes such as details of the frequency and nature of log damage. Types of log damage have been discussed in Chapter 1. For further details, refer to papers by Gabrielsson et al (1989), McIntosh (1968) and Williston (1979). Because it is relatively easy to tell if a log is broken or damaged, control charts for attributes can used to control the frequency of log damage. Log damage can be directly controlled, and value loss indirectly controlled. Reducing log damage will result in the recovery of volume which would not otherwise be recovered and an improvement in the overall value of logs recovered, both of which will increase the total log recovery value from the setting.
Data collection:

Data should be collected by an observer close enough to the yarding operation to observe when damage occurs and to also observe the conditions which contributed to the damage. It may be practical after the system has been implemented and acceptance has been gained of the usefulness of the system to have a member of the yarding crew record the observations (Maness, 1993). Prior to that time, however, a designated quality control officer should carry out the data collection. With a small amount of training, the crew members can become at least partly involved in the control process through participation in the analytical aspect of the system. This will result in greatly increased benefits from the control program. The key to getting the employees to willingly participate in the program is to make it clear that the results will not be used in any way to evaluate their individual performance. It should be stressed the objective is improve recovery, not to apportion blame or responsibility for errors (Scherkenbach, 1986).

The type of data to be collected would not be fixed until considerable experience has been gained in using the control methods. In the beginning, data collection would include as much information as it is feasible to collect about the type of damage and the conditions or circumstances surrounding the damage. It is best at this point to avoid attributing the damage to any one factor, as any attempt to limit the information collected will
create the possibility that some vital piece of information is overlooked.

**Analyzing a system:**

Using control charts to monitor a system is only part of the process of controlling special causes of variation and achieving predictability in a system. Completion of the process involves an in-depth analysis of the system. The objective is to determine where the most serious causes of variation occur and find out how to reduce them. Whereas control charts are primarily numeric, the tools used for this purpose are analytical, mainly observation and documentation of critical areas of a process. Particular emphasis is placed on periods when special causes of variation occur as indicated by the control charts. Specific tools used for this method include check sheets, histograms and Pareto charts.

**Check Sheets:**

Dey (1993) states that check sheets provide a disciplined approach to gathering factual information. Check sheets can be developed for any process. The key is to identify the critical factors. The check sheet is not necessarily limited by statistical considerations. It is only necessary to observe a process and record what is observed, with particular emphasis on causes of errors and what action was, or could be, taken to correct them.
Figure 4 is an example of a check sheet designed to gather information on the amount and type of log damage which occurs. The information from this check sheet can be used as input to a control chart for attributes. A column of the checksheet would be used for each log. Each time a log is observed as damaged, a mark would be placed opposite the type or types of damage. The total number of logs in the sample would be tallied using some form of mechanical tally device.

Figure 4. Checksheet for damage type (partial).

<table>
<thead>
<tr>
<th>SAMPLE NO.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAMAGE TYPE:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BROKEN TOP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BROKEN END</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHATTERED END</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SLABBED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOP SLABBED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BROKEN BUTT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BUTT SPLIT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OTHER:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL LOGS YARDED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL LOGS DAMAGED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5 is a check sheet focused on the causes of log damage and the conditions existing at the time of the damage. Since there can be more than one contributing factor to a damage occurrence, data from this type of checksheet is not usually used for statistics on numbers of logs damaged, but can be used for further analysis of causes of damage.
The checksheet for damage types can be combined with the checksheet for damage causes and conditions to make one data collection form which can be used in the field. For an example of this combined form, see Chapter 4, recommended quality control system. Once a number of samples has been taken, the data in the damage type section on the number of logs yarded and damaged can be transferred to a process control chart for further analysis. The damage causes section of the check sheet will provide details necessary for further investigation of special variation when it occurs in a sample.

**Histograms and Pareto charts:**

Histograms are an often overlooked means of showing graphically which types of problems occur most frequently. They can be used to determine where problem solving efforts should be concentrated. In Figure 8 (Chapter 3), a histogram is used to analyse the frequency of various types of log damage that occurred during the pilot study.
Pareto charts are an easily used method of analyzing data. As mentioned by Juran and Gryna (1993), they are based on the Pareto Principle which states that a small number of the causes of loss is often responsible for a large amount of the loss. Figure 9 (Chapter 3), is an example of a Pareto chart.

With a Pareto chart, causes of variation are ranked according to frequency of occurrence, effect on cost, or some other relevant basis. The Pareto chart in Figure 9, shows these causes ranked in order of descending value loss based on the actual data collected during the pilot study. The chart also shows the cumulative value loss as a result of the causes. Figure 9 shows which causes have the greatest effect and where efforts can be concentrated to achieve the greatest improvement. In Figure 9, the cumulative loss line shows that nearly 80% of the value loss is of two types, broken ends and split butts. As experience is gained, the information collected will be refined to suit the circumstances. The Pareto chart categories can be modified as appropriate.

Once a system has been analyzed and special causes of variation investigated and removed (where cost effective), the first phase of quality control has been achieved: The system is under control.

**Phase II: Continuous improvement:**

Continuous improvement is the next step after bringing a process under control. All aspects of the system remain under constant
scrutiny, by both workers within a system and by management, looking for ways to increase quality and improve productivity. Traditionally, woods workers have not been encouraged to contribute to the process of improving the system. To be successful in achieving continuous improvement, management must recognize that the workers have a detailed knowledge of the system. They should be the first source of ideas for improvement. These ideas do not have to be revolutionary but merely contribute to the process of improvement in some way. Experience gained during the process of implementing a comprehensive quality control system at the Carter Holt Harvey Ltd. (CHH) sawmill in Taupo, New Zealand (Collins, 1993), has shown that it is better to have many small improvements than to attempt a major improvement with one change. At this mill all employees were involved in the process of improving quality, with significant gains in recovery and safety.

Continuous improvement can be monitored and observed using Shewhart charts over an extended period of time. As continuous improvement efforts take effect, this should be reflected in a gradual and continuous narrowing of the upper and lower control limits and lowering of the average level of defects. Common and special variation have been discussed above. Phase II is concerned with reducing the normal operating limits due to common variation so that even if special variation causes the process average to be shifted beyond the normal operating limits, the product specification limits will not be exceeded (Maness, 1993). The product specification limits are the limits set by the
customer, such as a sawmill, and represent the customers desired level of quality. To achieve what is in effect a safety margin between the desired output and the actual output, the common variation of the system must be reduced until the normal operating (6 times Standard Deviation) limits of the output of the system are narrower than the product specification limits by the largest possible amount of special variation. The benefit of reducing common variation to this level, is that even if something goes wrong with the process, and the safety margin is used up, the product will still be within the customers specification limits.
CHAPTER THREE - PILOT STUDY

The literature review has demonstrated that there is a number of techniques which can be used to help control the effect of yarding operations on log recovery value. The next step in the development of an effective method of controlling losses is to perform a field study of the operating conditions and constraints occurring in yarding operations on the coast of British Columbia. This will help to ensure that methods developed for controlling yarding operations will function effectively under actual operating conditions.

In order for a field study to be effective, it should be designed to measure a particular factor. A factor which should be known for the development of cost effective quality control procedures is the long run average loss in recovery value and the variability in that value. This factor is the basis for determining where and how much effort should be spent on controlling variation. The difficulties of implementing procedures for controlling and improving the production process must be offset by an improvement in the average loss due to damage if there is to be a net benefit to implementing the procedures. It was decided, therefore, that a pilot study would be conducted to develop and test procedures for determining average value loss under several different commonly used yarding systems. This information could be used to evaluate further measures to implement production control procedures. Cost
estimates of proposed control procedures were beyond the scope of this study.

Data collected was used to calculate base line data for the systems used in the pilot study. This demonstrated the effectiveness of the methods proposed for data collection and analysis. The problems encountered were evaluated and solutions developed or suggested where relevant to the development of quality control methods for yarding.

Methods:

A site for the pilot study was made available through cooperation with the Forest Engineering Institute of Canada (Western) (FERIC) and Fletcher Challenge Canada Limited (FCC). The site was typical of a setting in a low elevation Cedar-Hemlock-Balsam stand on the west coast of Vancouver Island. The trees in the setting were felled and bucked prior to any measurements. Three types of yarding systems were used in the setting, providing the opportunity to develop base line data for three systems. Table 3 shows the relevant details of the site characteristics and Table 4 shows the details of the yarding systems for each area. The Appendix contains location and setting maps.
### Table 3. Site characteristics.

<table>
<thead>
<tr>
<th>Units</th>
<th>SKYLINE</th>
<th>GRAPPLE</th>
<th>HIGHLEAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>AREA</td>
<td>Hectares</td>
<td>3.5</td>
<td>4.7</td>
</tr>
<tr>
<td>SLOPE-average</td>
<td>Percent</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>SLOPE-range</td>
<td>Percent</td>
<td>0 - 20</td>
<td>5 - 20</td>
</tr>
<tr>
<td>TERRAIN ROUGHNESS</td>
<td></td>
<td>GENTLY ROLLING</td>
<td>UNBROKEN SLOPE</td>
</tr>
<tr>
<td>ESTIMATED VOLUME</td>
<td>Cubic Metres</td>
<td>2,900</td>
<td>3,900</td>
</tr>
<tr>
<td>ESTIMATED VALUE</td>
<td>$</td>
<td>306,000</td>
<td>411,000</td>
</tr>
</tbody>
</table>

The volume estimates were based on the average volume per hectare for the opening obtained from the operational cruise of the area. The value estimates were based on the volume estimates and the average market value per cubic metre of the logs sampled for each area (Average domestic log selling prices for major coastal loggers; for the month ended December 15, 1992).

Table 4 shows the yarder type, cable system and other characteristics of the yarding systems.
Table 4. Yarding system characteristics.

<table>
<thead>
<tr>
<th>YARDER TYPE</th>
<th>SKYLINe</th>
<th>GRAPPLE</th>
<th>HIGHLEAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swing Yarder</td>
<td>Cypress Model 7280</td>
<td>Swing Yarder</td>
<td>Mobile Spar</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cypress Model 7280</td>
<td>Madill Model 901</td>
</tr>
<tr>
<td>CARRIAGE TYPE</td>
<td>Butt Rigging W/ chokers &amp; Rider block</td>
<td>Grapple &amp; Rider Block</td>
<td>Butt Rigging W/ chokers &amp; Rider Block</td>
</tr>
<tr>
<td>TAILHOLD</td>
<td>Backspar tree</td>
<td>Excavator/ Stump</td>
<td>Excavator/ Stump</td>
</tr>
<tr>
<td>CABLE SYSTEM</td>
<td>Running Skyline</td>
<td>Running Skyline</td>
<td>Running Skyline</td>
</tr>
</tbody>
</table>

Each area is labeled according to the common term for the type of system used in that area; skyline, grapple or highlead. All three systems are technically running skyline systems because of the addition of the rider block to increase lift in each case. The major differences between the three systems were the two means of connecting the logs to the system (chokers and grapple) as used by the Skyline and Grapple systems and the two yarder types (swing yarder and mobile spar) as used by the Skyline and Highlead systems.

**Data collection:**

To determine value loss it was necessary to measure and grade a number of logs prior to yarding and then examine them after yarding for any damage. Value change would then be determined based on the change in volume and grade of the log using published open market log values.

The basis for selection of the logs was to provide an adequate sample of all species of logs on the site. As yarding distance could be a factor in the amount of damage, samples were taken
uniformly over the range of yarding distances to minimize the effect of yarding distance on the results. Particular attention was given to selecting lumber and shingle grades of logs as they were deemed more likely to suffer significant value loss than pulp grade logs. It was attempted to select different species in approximately the same proportions as in the original stand.

Logs were selected at random using the guidelines stated below. A target of 200 logs for each area was set, however due to changes in the system area boundaries, this target was not reached in the skyline area.

The criteria for selection of logs in the field were:

• The log was not rotten or damaged prior to yarding as indicated by examination of the visible surface of the log. Rotten logs were excluded because of the difficulty in estimating the deduction for rot required on a consistent basis.

• The log was bucked at both ends. Selecting logs which were already broken would create bias in the results. This is because the potential for loss with these logs would be less than with logs which were intact when measured. Large cedar logs which were split or partially split from falling were also excluded for the same reason.

• Enough of both ends of the log was visible to scale and apply identification numbers and tags. Where it was uncertain whether a log could be scaled, it was selected
and left up to the scaler's discretion to decide whether it could be scaled or not. Some errors in the field scale were found when the logs were examined at the landing which were adjusted by rescaling and correcting the field scale.

In order to select the target number of logs in each area, it was necessary to select as many of the logs which met the above criteria as possible. A sampling plan such as a line transect or variable size plot methods was not used because it would probably have resulted in reducing the number of logs selected below the target levels. Table 5 shows the details of the logs sampled for each area:

Table 5. Sample statistics.

<table>
<thead>
<tr>
<th>Units</th>
<th>SKYLINE</th>
<th>GRAPPLE</th>
<th>HIGHLEAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>NUMBER</td>
<td>pcs</td>
<td>151</td>
<td>269</td>
</tr>
<tr>
<td>VOLUME</td>
<td>m³</td>
<td>816.3</td>
<td>1337.8</td>
</tr>
<tr>
<td>VALUE</td>
<td>$</td>
<td>109,000</td>
<td>170,000</td>
</tr>
<tr>
<td>AVERAGE VALUE/PC</td>
<td>$/m³</td>
<td>133.73</td>
<td>132.58</td>
</tr>
<tr>
<td>AVERAGE SIZE/PC</td>
<td>m³</td>
<td>5.40</td>
<td>4.80</td>
</tr>
<tr>
<td>MINIMUM VOLUME/PC</td>
<td>m³</td>
<td>1.03</td>
<td>0.51</td>
</tr>
<tr>
<td>MAXIMUM VOLUME/PC</td>
<td>m³</td>
<td>25.08</td>
<td>23.84</td>
</tr>
</tbody>
</table>

A licensed scaler was supplied by FCC to measure and grade the logs in order to achieve consistency and accuracy of
measurements. The scale was based on the gross measurements and visible physical characteristics of the log. No deduction was made for hidden defects, in order to minimize inconsistencies in scaling.

Data recorded by the scaler at the felling site included:

- Log number
- Species
- Statutory (Ministry of Forests) grade
- Log length to nearest 0.2 metre
- Top and bottom diameters in Rads (radius in centimetres)

The landing scale was preceded by a visual inspection of the log. Only logs which had visible damage or appeared to have been incorrectly scaled in the field were rescaled at the landing. This substantially reduced the amount of scaling time involved with no loss of information because only a change in volume or grade was of interest in the study.

To facilitate identification of logs at the landing, all logs were numbered in a manner that would withstand the rough treatment the logs would receive in the yarding process. A numbered aluminum tag was fastened to the butt of the log with an aluminum nail. If two logs were so close together that the butt of the selected log was not accessible, a bevel was cut in the end of the log, deep enough that the tag could be fastened and would be visible when the log was yarded. Logs were also numbered using log marking paint and lumber crayon. It was
important that either the marks or tags be visible from the end to identify logs in piles or truck loads.

To keep track of all logs that were examined at the landing, records were kept of the numbers of marked logs on each loaded truck along with the load ticket number, truck number, date and comments concerning any damage to the log. These comments provided the basis for the analysis of damage by type.

Data analysis:

The scale data was received from the scaler on a computer disk and imported into a spreadsheet file. The landing scale data and other damage related information were entered manually into the spreadsheet and matched with the original scale data. Separate listings and summaries were prepared for the three different harvesting systems. Logs which were yarded by a system different than originally planned were transferred to the appropriate sample listing. For logs which were not scaled at the landing, the field scale data was used for the landing scale, to make comparisons possible on a total basis for each system. Any logs for which scale data was obviously mismatched indicating an error in observing log numbers, scaling, or in recording data were eliminated from the sample.

Log volumes were compiled using Smalian's formula. As a check on the accuracy of the compilation, the volumes calculated for each log were compared to the volumes which had been calculated by the scaler using the same data.
The volumes and grades based on the field scale and the landing scale were compared on a log by log basis and any differences were attributed to the effects of yarding. Logs which were not examined at the landing were excluded from the population of sampled logs.

The value loss associated with each damaged log was estimated using published December, 1992 Vancouver Log Market values for each species and grade category according to the British Columbia statutory grading system. These values were considered representative of open market log values over the period of study. The purpose of using the Open Market log values was to weight the loss for the higher grade logs. Because only the relative change in value was being measured, no deduction was made for hauling, sorting and other costs associated with getting the logs to market.

Loss in market value was determined for each system. The losses were calculated in percent of total value yarded to provide a fair means of comparison.

Results:

The results of the pilot study are shown below. These are: an estimate of the average loss for the yarding systems used in the study, and a summary of the problems encountered during the study and how they would be dealt with in the recommended quality control method.
Average value loss:

The average value losses for each system and in total as found by the study are shown in Table 6. Total damage includes value loss due to both volume loss and grade change. These loss factors were grouped together because under the grading rules used, grade is partially dependent on the same physical dimensions that determine volume.

Table 6. Loss in recovery value by system.

<table>
<thead>
<tr>
<th></th>
<th>SKYLINE</th>
<th>GRAPPLE</th>
<th>HIGHLEAD</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOGS DAMAGED (Pieces)</td>
<td>3</td>
<td>7</td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>TOTAL VALUE LOSS ($)</td>
<td>1,253</td>
<td>1,351</td>
<td>2,176</td>
<td>4,781</td>
</tr>
<tr>
<td>AVERAGE VALUE LOSS (% OF SAMPLE $)</td>
<td>1.1</td>
<td>0.8</td>
<td>1.6</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Table 6 shows that the average value loss was 1.2% with losses ranging in value from 0.8% for the grapple system to 1.6% for the highlead system. These results are within the range of results expected from the literature review. The number of logs damaged in each system was very small relative to the number of logs sampled. Because of this, it was concluded that analysis of the types of damage would be more appropriate than a statistical test to determine if there was any difference between the results for each system. This approach is consistent with the objective of the pilot study which was mainly the development and testing of methods. The conclusion above indicates that a much larger sample would be required to ensure that enough damaged logs occur
in the sample to perform statistical comparisons of the results. For this reason, it was decided to investigate methods which would not require such extensive sampling for the amount of information gained, such as checksheets and control charts for attributes. Examples of how the results would be monitored using control charts for attributes and how detailed analysis of the damage would be done are shown in the following sections. Recommended procedures for using checksheets and control charts are discussed in Chapter 4.

The above results demonstrated that average value loss can be estimated using the methods developed for the pilot study. However, because this was a pilot study, the methods used and the problems found are of more importance than the results. In view of the number and the nature of the problems encountered in the study, the results should be used with extreme caution. The problems are discussed below.

**Monitoring log damage:**

The damage to logs resulting from yarding over the periods in which logs were scaled is shown in Table 7 and plotted on a control chart in Figure 6. Although the periods roughly correspond to a week, this is not entirely so, because in the third week of yarding, the type of yarding system changed from skyline to grapple. Because this is a change in the rational subgrouping, the sample for this week was split into two periods:
Table 7. Yarding results and statistics by period.

<table>
<thead>
<tr>
<th>PERIOD</th>
<th>LOGS SCALED</th>
<th>LOGS DAMAGED</th>
<th>PROPORTION DAMAGED</th>
<th>UPPER CONTROL LIMIT</th>
<th>YARDING SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>0</td>
<td>0.000</td>
<td>0.125</td>
<td>Grapple</td>
</tr>
<tr>
<td>2</td>
<td>77</td>
<td>0</td>
<td>0.000</td>
<td>0.075</td>
<td>Skyline</td>
</tr>
<tr>
<td>3</td>
<td>87</td>
<td>3</td>
<td>0.034</td>
<td>0.072</td>
<td>Skyline</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>2</td>
<td>0.050</td>
<td>0.095</td>
<td>Grapple</td>
</tr>
<tr>
<td>5</td>
<td>140</td>
<td>4</td>
<td>0.029</td>
<td>0.062</td>
<td>Grapple</td>
</tr>
<tr>
<td>6</td>
<td>50</td>
<td>1</td>
<td>0.020</td>
<td>0.087</td>
<td>Grapple</td>
</tr>
<tr>
<td>7</td>
<td>30</td>
<td>0</td>
<td>0.000</td>
<td>0.106</td>
<td>Highlead</td>
</tr>
<tr>
<td>8</td>
<td>60</td>
<td>3</td>
<td>0.050</td>
<td>0.082</td>
<td>Highlead</td>
</tr>
<tr>
<td>9</td>
<td>70</td>
<td>0</td>
<td>0.000</td>
<td>0.077</td>
<td>Highlead</td>
</tr>
<tr>
<td>10</td>
<td>63</td>
<td>1</td>
<td>0.016</td>
<td>0.080</td>
<td>Highlead</td>
</tr>
<tr>
<td>11</td>
<td>15</td>
<td>1</td>
<td>0.067</td>
<td>0.140</td>
<td>Highlead</td>
</tr>
<tr>
<td>12</td>
<td>8</td>
<td>0</td>
<td>0.000</td>
<td>0.183</td>
<td>Highlead</td>
</tr>
<tr>
<td>13</td>
<td>21</td>
<td>1</td>
<td>0.048</td>
<td>0.122</td>
<td>Highlead</td>
</tr>
<tr>
<td>14</td>
<td>5</td>
<td>0</td>
<td>0.000</td>
<td>0.226</td>
<td>Highlead</td>
</tr>
</tbody>
</table>

Scaling of marked logs began in Period 1 (June 18), with logs being grapple yarded to the roadside, scaled, and loaded out immediately. Then, beginning in Period 2 (July 1), logs which had been previously yarded and windrowed with the swing yarder and chokers, were scaled concurrently with loading. In Period 4 (July 9), loading and scaling of the main portion of the grapple yarded logs which had also been yarded previously and windrowed, began. Following a shut down from August 1 to November 11, highlead yarding began in Period 7 (November 12). Logs were
yarded, scaled and loaded out the same day, which continued until Period 14 (February 25).

Figure 6. Control chart for log damage (study data).

Figure 6 shows that the proportion damaged did not exceed the upper control limit during any period. The upper control limit varies greatly between periods due to the large range of logs scaled each period. This situation is very likely to occur under actual operating conditions, because combinations of various factors can cause daily or weekly production to fluctuate significantly. A problem which arises because of the shift in the upper control limit is that shifts in the average may not be what they appear to be at first glance. For example, the proportion damaged in Period 8 (0.50) appears lower on the chart than the proportion damaged in Period 11 (0.67). However, because the upper control limit increases from 0.082 in Period 8 to 0.140 in Period 11, the proportion damaged in Period 8 is
actually closer to being out of control than in Period 11.

Duncan (1965) discusses this problem, caused by large changes in sample size. He suggests the preparation of a stabilized chart in such cases, where the values being recorded are expressed in units of the standard deviation, instead of proportions. Figure 7 shows how the scaled logs for the fourteen periods would appear in a stabilized chart.

Figure 7. Stabilized control chart for log damage.

In Figure 7, the proportion damaged in Period 8 is now closer to the upper control limit than in Period 11. Stabilized charts should be prepared in addition to standard control charts before analyzing the patterns of recorded points when sample sizes vary greatly. Standard control charts should be used in any discussions with people not familiar with statistical concepts, because of the increased complexity of the concepts involved in the stabilized chart.
With stabilized charts it is also possible to place warning limits at one and two sigma (σ) levels without significant additional calculation. If warning limits are set at the one sigma level, in this case, Periods 4, 8 and 11 would be outside the warning limit and would be investigated more closely.

The pattern of the points in Figure 7 does not meet any of the criteria for judging out of control situations as discussed above. Therefore it can be concluded that the changes from one yarding system to another that occurred during the study did not have an effect which could be distinguished from random variation. Because the effect of the changes, if any, cannot be distinguished from random variation, the changes cannot be classified as special or assignable causes of variation, and therefore, any variations in the results from sample to sample cannot be attributed to the changes in the yarding system.

**Analysis of Damage:**

The frequency of damage by different types is shown in the histogram in Figure 8. This chart shows that broken tops and slabbing are the most frequently occurring types of damage.
The Pareto chart in Figure 9 shows the relative value losses from different types of damage.
From this Figure, it is evident that the largest value loss occurs as a result of broken ends, $1,951, with the next largest loss arising from butt splits, $1,757. Together, these two types of losses account for nearly 80% of the value lost. This finding is consistent with the Pareto Principle as discussed above. The conclusion from this analysis is that efforts to reduce damage loss by reducing broken ends will provide the greatest gains in value recovery.

**Procedural problems:**

The major problems encountered in applying the procedures developed for the study were:

**Number of logs to be marked:**

It was recognized at the start of the study that accurate measurement of losses during the yarding phase could only be achieved by measuring logs both before and after yarding. The pre-yarding dimensions of broken logs could not be estimated after yarding by measuring their component parts, mainly due to the problem of locating and identifying the broken bits which get left in the field. Obviously, it was not possible to tell in advance which logs would be broken, nor in which areas the breakage would occur. Also, only a small percentage of logs was expected to be broken, though not as few as actually occurred. These factors meant that a large number of logs spread evenly over the study area had to be measured in order to ensure that a representative sample of damaged logs would be obtained.
Recording and analysing the data was very time consuming with so many logs sampled. The recommended quality control system is based on detailed recording of circumstances associated with the logs which are actually damaged, and should therefore reduce the amount of recording and analysis time.

Productivity:

Productivity for the marking phase of the study was reduced by the difficulty in locating sufficient logs which met the selection criteria. Slash, other logs and heavy brush were the largest impediments to movement on the ground and selection of logs. The conditions were considered normal for recently felled stands on the west coast of British Columbia. Actual productivity of marking was from 20 to 40 logs per day by a two-person crew depending on the brush conditions and the condition of the logs. About 750 logs were selected, requiring 25 working days to tag and mark. The total time taken for marking, although necessary for obtaining baseline data, would not be acceptable under operational conditions, and therefore further supports the recommended quality control system.

Scaling difficulties:

It was difficult to see enough of the log in some cases to measure and grade it accurately. Where the scaler judged that he could estimate the measurements with reasonable accuracy, this was accepted. The alternative to accepting some reduction in the level of accuracy would be to drastically reduce the number of
logs available for selection and reduce the effectiveness of the study. Under current coastal operating conditions, this will be a common occurrence, and it may be difficult to overcome this problem unless alternate methods are developed not requiring scaling in the field.

Coordination with operations:

One of the problems with scaling at the landing was being able to examine and scale the selected logs while yarding and loading operations were in progress. The main concern was the safety of the scaler and study personnel. It was necessary to carry out the examination and scaling of the logs in the area where the loader, and sometimes the yarding machine, were operating. Logs were constantly being moved by both machines. The problem was resolved in the pilot study through coordination with the loader operator. The operator scanned the logs as they were being swung out of the way of the yarder or removed from the windrow pile and signaled the scaler if any logs had markings on them. The loader operator also swung the logs to one side if it was necessary for the scaler to examine the log more closely. For longer-term studies of value losses and successful implementation of a quality control system, procedures need to be developed which do not interfere with operations.

Identifying logs:

A major problem anticipated at the beginning of the study was the difficulty of identifying selected logs in a way which would
withstand the forces of yarding and still be readily visible from a distance and at the landing. Different types of marking systems were considered, but the best solution appeared to be a combination of all three types available: tags, log marking paint, and crayon. Improvements are still needed in the methods of marking and identifying logs as indicated by the fact that 0.5% of logs were not accounted for in the Highlead area, the last area to be marked and yarded.

Sensitivity of scaling to log quality factors:

The statutory grading system is dependent on physical dimensions and some of the quality characteristics of the log. Quality characteristics which can effect log value, such as bark removal, scraping, and gouging, and other types of damage which may happen to logs during yarding operations, are ignored if the effect on grade or volume is not significant. Logs which did not show sufficient damage to change these factors under the current grading system were not rescaled, although they might have had damage of the above types which would result in a significant drop in recovery value at the sawmill. Producers in other countries have developed elaborate grading systems which recognize the needs of different markets. Log grading systems for coastal operations need to be developed based on end use products in order to maximize the recovery value of logs and minimize waste. For the purposes of determining base line data on value loss, use of a sawing simulator to estimate the volume of various grades of products which could be produced from the
selected logs should be investigated. This is beyond the scope of this thesis.

Bias in log selection:

Logs were selected according to the criteria given above. Although a large number of logs was selected, the selection was not entirely representative for two reasons:

Low value pulp logs were selected relatively less frequently than high value lumber grade logs. The basis for this was that the potential value loss for pulp grade logs would be small because their value was already very low. Pulp logs can suffer a value loss because, even though they are in the lowest statutory grades, there is still a narrow range of values for them. The emphasis of the pilot study was on testing methods of measuring the loss in log value resulting from log damage. Therefore, the considerable extra effort required to obtain a representative sample of all log sizes was not considered to be worthwhile. This policy would undoubtedly cause some undetermined bias in the results.

Another source of bias results from the fact that logs which were buried under piles were less likely to be included in the sample because of the difficulty of measuring and scaling them. This would have an effect on the average value loss because logs which were buried under piles of other logs would be more likely to be broken when the logs are pulled out of the pile by the yarder. The amount of bias caused by this omission could be significant.
Without further study, the amount of the bias is impossible to estimate.

*Unexamined logs:*

A number of logs were selected which were not examined at the landing. There are two main reasons why these logs were not accounted for: they reached the landing in one or more pieces which were not identified because the tags or other marking were missing or not visible, or they were broken up during yarding and no identifiable pieces reached the landing.

If the logs had simply been missed at the landing, but were not damaged, the measured average loss would be unbiased because missing logs were excluded from the sample. On the other hand, if the logs had actually been broken in yarding and not recovered, the average value loss would be understated because no loss was recorded for missing logs. How many of the missing logs were actually broken is not known. A residue survey of the setting was done by FERIC after yarding, and no marked logs were observed, which would tend to support the conclusion that most of the missing logs actually reached the landing but were not identified. Further study should be done on the problem of adequately marking the logs when collecting base line data on damage losses. The recommended quality control method reduces this problem by making notes on log damage as the logs are being yarded, thereby making it unnecessary to mark logs.
Recovery improvement information:

Data necessary to calculate value loss was collected on each log that was inspected at the landing. However, only minimal information related to the type of damage or the causes was recorded. This was due mainly to the constraints imposed by the study design and the operating conditions. Difficulties in identifying logs and observing and recording events during the yarding process stemmed partly from the large number of logs which were selected. More detailed information on the type of damage and the causes would be useful in efforts to improve methods and reduce value loss. The recommended quality control system is designed to provide this information.

Value and grade relationship:

The estimate of value loss would be considerably more useful for making management decisions if a set of values had been available which reflected the actual value of the various grades of products which could be produced from the logs. However, these types of values are not available for logs from old-growth forests, on the coast of British Columbia, on a current basis, in spite of the high values that are involved and the significant effect that mill recovery can have on log recovery value. At present the only values that are available are based on the statutory grading system which is based primarily on treating logs as a commodity product. Statutory grades are based on generalized physical characteristics as defined in a set of rules which do not change with market conditions. The market value of
a log based on the statutory grades may vary substantially from the actual value of the log to an individual converting mill. As a result, estimates of average loss based on these values may be misleading.

An approach to this problem which should be studied further, is to use a sawing simulator to determine the value of logs, before and after yarding, based on the potential recovery of various products from the logs. It would be necessary to obtain current market values which could be related to the grades determined by the simulator. It would probably be easier to do this and let the simulator carry out the conversion of the logs, rather than to try to develop a system of log values based on the grade of a whole log. This would also require very detailed assessment of log dimensions and condition. Development of this approach should also help to resolve problems of scaling logs as discussed above.
CHAPTER FOUR - RECOMMENDED QUALITY CONTROL METHOD:

The primary objective of this thesis was the development of a quality control system to control losses in log recovery value in yarding operations. The method must be practical and usable under operational conditions. The literature review has shown how control charts and other statistical tools can be used to control value loss. The pilot study has shown some of the problems which have to be considered in the development of the methods. The following quality control procedures are recommended as a means of meeting the objectives.

Operational quality control procedures:

The procedures recommended for controlling log damage under operational conditions consist of two major components:

• a checksheet for gathering information in the field on the prevailing conditions, the types of damage, and the possible causes of damage which occurs during yarding, and

• a control chart for displaying over time, the pattern of variation of the proportion of logs damaged as determined from the information recorded on the checksheet.

The application of each of these components is discussed below.

Checksheet for recording damage information:

A checksheet is the most suitable means of collecting the data. The form should allow for description of the operating conditions
at the time of the sample and the possible reasons for the damage or breakage. The forms should be designed so the frequency of different causes can be tallied for further analysis.

An example of a checksheet designed for this purpose is shown in Figure 10.

**Figure 10. Checksheet for yarding damage assessment.**

<table>
<thead>
<tr>
<th>YARDING DAMAGE CHECKSHEET</th>
<th>DIVISION</th>
<th>SETTING NO.</th>
<th>PERIOD</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOG NO.</td>
<td>1 2 3 4 5 6 7 8 9 10 11 12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DAMAGE TYPE:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BROKEN TOP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BROKEN END</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHATTERED END</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLABBED</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOP GLABBED</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BROKEN BUTT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BUTT SPLIT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OTHER:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TOTAL NUMBER OF LOGS DAMAGED</th>
<th>LOG NO.</th>
<th>1 2 3 4 5 6 7 8 9 10 11 12</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>YARDING CONDITIONS:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BREAKOUT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HANGUP ON STUMP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GULLEY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LANDING</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>YARDING MACHINE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>YARDING SYSTEM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ENGINEER</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WEATHER</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>SLOPE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TERRAIN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STAND AGE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CABLE RIGGING</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO OF CROKERS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRAPPLE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEFLECTION</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>YARDING DISTANCE</td>
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<tr>
<td>OTHER:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TIME</th>
<th>DATE</th>
<th>OBSERVER</th>
<th>NOTES:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>RECORD OBSERVATIONS OF BOTH DAMAGE TYPE AND CONDITIONS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>USE MECHANICAL COUNTER OR OTHER METHOD TO TALLY LOGS YARDED</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RECORD AS MANY CONDITIONS AS APPROPRIATE</td>
</tr>
</tbody>
</table>
Periodically, for example, weekly, a number of logs yarded in a given setting are sampled by observing them being yarded and recording any damage that occurs to them. As discussed above, the most important factor to be considered when determining the sample size and frequency of sampling is the rational subgroup. The recommended sampling method is to observe a full day's yarding with each sample, to obtain as large a sample size as possible, however, each sample should coincide with a period of similar operating conditions. Therefore, if a change occurs in the yarding conditions during the day, such as a change in terrain, or a change in the yarding machine or operator which could have an effect on the proportion of logs damaged, a new sample should be started.

The frequency of sampling depends on the level of damage currently being experienced. If the level is high, the frequency of observations will have to be increased, to perhaps daily. Once the frequency of damage has been reduced to acceptable levels, the frequency of observations can also be reduced. The determination of acceptable levels will depend mainly on cost and benefits of sampling as discussed above.

Actual observation of damage will begin when the log starts moving toward the landing and ends when it reaches the landing. The observer should be in a position to observe the logs throughout this operation. The observer will need to be in radio contact with the yarding machine operator, to enable him to request that specific logs be set aside at the landing for
inspection. If a log is damaged and only part of the log reaches the landing, the observer will estimate the proportion of the log which is lost. Exact measurement of the lost portion is not required, as the value does not need to be calculated.

Many different types of damage can occur more or less frequently, and the observer will need to make careful notes, including diagrams, if necessary, to fully document the damage. The criteria for recording damage should be to record any type of damage which affects the value of the log or the potential products which can be produced from the log. Judgment will be required, particularly in the early stages of the implementation of the quality control system. Consultation between the observer and a prospective end user of the log, such as a sawmill or log trader, should take place to resolve questions as to the effects of various types of damage on recovery value.

Observations during the yarding process combined with inspection at the landing in accordance with the above guidelines should be sufficient to determine the frequency, type, and severity of damage. After the system has operated for a while, the methods should be evaluated to determine if they are operating effectively and changes made as necessary in the criteria for assessing damage.

Once the quality control system has been implemented on a periodic basis and the problems in data recording that arise have been dealt with, consideration can be given to having the checksheet maintained on a continuous basis by a member of the
Yarding crew such as the engineer or hooktender. Although this would require some investment in training to achieve this goal, it is an ideal arrangement because the crew would then be responsible for monitoring its own performance. This should provide more relevant information and reduce the overall staffing required to collect the data. However, it is not likely that this would be feasible without improvements in current industry labour-management relations. The checksheet should be used from the beginning as the basis for informal discussions between crew-members and supervisors on quality and damage control. Because yarding crews consisting of two to six workers are all involved in the process of yarding as a team, any control procedure should be applied to the crew as a group or team, rather than as individuals. Discussions of quality considerations and actual participation in the control process, will help to improve the effectiveness of the system.

**Control chart for monitoring log damage:**

A control chart for attributes would be used to monitor log damage. The control chart would show the pattern of log damage over an extended period of time using information from the checksheets.

An example of a control chart for attributes designed for this purpose using sample data is shown in Figure 11.
Figure 11. Control chart for yarding damage.

The example provides room for up to 12 twelve samples but can be modified to accommodate more samples to provide a longer term view if required. The calculation of the control limits and plotting of the data were covered in the literature review. The example shows how the control limits would vary with a varying sample size. In this example, sample sizes were relatively consistent, therefore it was not necessary to prepare a
stabilized control chart as discussed above. The advantage to using proportions in the chart rather than standard deviation units is that the chart will be easier to understand by people who are not familiar with statistics. If large variations in sample size occur, stabilized charts should be prepared in addition to standard charts, and the results discussed only with management and others who are familiar with statistics.

The control limits calculated initially should be considered preliminary limits. As a detailed history of log damage is created through successive samples, the normal operating pattern should become evident. The length of the initial period will depend on how long it takes for everybody involved in the data collection process to become familiar with the requirements, and for necessary modifications to be made to the checksheets and control charts. Establishing control of the process will result in a improved long term process average.

**Long term application of control charts:**

When the initial period has passed, the control limits should still be recalculated periodically, for example monthly, because of long term reductions in the process average resulting from the implementation of the quality control program. Long term control limits should be calculated using the moving average method, with a sliding period such as two to three months, which should provide enough time to eliminate short term fluctuations. Long term control limits may also be adjusted to reflect the objectives of the chart. For example, lowering the upper control
limit would cause more effort to be spent on investigating special causes of variation. On the other hand, if management decides that current performance levels are acceptable and that problem investigation efforts should be concentrated in other operating areas, such as falling and bucking, the control limits could be raised. Only very seriously out of control situations would then be investigated.

Charts should be distributed as soon as they are prepared, which should be on a regular basis, to both the workers and the supervisors who are involved in the operations being monitored. The charts can be discussed in informal meetings with the crew, along with the checksheets as mentioned above. As people become familiar with the charts and checksheets, the workers who are being monitored by the charts can become more involved in the preparation of the charts. For example, once long term control limits have been established, they can be put on the charts in advance and the only thing that needs to be plotted is the percentage of logs damaged in each successive period, which could be done by one of the crew-members.

The timeliness of the review of the charts with the crew is very important. Except under very unusual conditions, there is no reason why the charts cannot be prepared in the field and shown to the yarding crew which has just been observed, preferably at the end of the same day on which the observations are made so that the details of the conditions will still be fresh in their
Comparing the recorded data with their impressions should provide valuable insight into causes of variation.

A benefit of keeping continuous records of log damage and breakage performance on a setting by setting and crew by crew basis would come from increased awareness of the frequency of breakage by all concerned, including the crews. By monitoring the number of logs damaged using the above methods, a simple and straightforward but detailed history of performance can be developed. Every member of the crew will thus become conscious of their performance and will see the times when it is better or worse than average with a positive, problem solving attitude. They will also appreciate more fully the need to reduce damage and will be drawn into the process of improving performance. This sense of participation is likely to be one of the most effective tools in improving performance and value recovery.

Analyzing the system:

Histograms and Pareto charts can be used to further analyze data gathered and assist in eliminating special causes of variation. Examples of these types of statistical tools have been discussed in the literature review. The uses of analysis tools and the processes of problem solving are complementary to control charts. However, further discussion is beyond the scope of this thesis.
CHAPTER FIVE - DISCUSSION:

Literature review:

The literature review has shown that control charts for attributes can be used where measurement of a variable is impractical. Damage to a log is an attribute which can be determined by visual inspection. Control can be established by monitoring individual log damage and providing feedback to workers and supervisors on the results of operations.

In the discussion of the relationship between sample size and sensitivity of the sample, it was shown with the use of operating characteristic curves, that larger sample sizes are better at detecting changes in the process average. Sample sizes were estimated using methods suggested by Juran and Duncan, both of which indicate that a sample of approximately 440 logs is required to detect a shift of 3σ with a 95 percent certainty.

The discussion also described how the criteria for determining out of control points in control charts are based on the assumed random nature of the variation in a system which is under control.

The literature review discussed methods of analysing a system including checksheets. Information leading to development of ways of reducing log recovery value losses can be collected at the same time that logs are being monitored for damage by using a properly designed checksheet.
Pilot study:

An essential first step in the development of any quality control program is determining the operating characteristics of the system. In this case, value loss in yarding is the characteristic of concern. It is important, therefore, to have some knowledge of the actual losses which are occurring. The initial tests performed in the pilot study provided some of this essential knowledge in the form of base-line data for several different systems used in the yarding, through comparisons of log values before and after yarding. The results indicated value losses were approximately 1 percent, which is consistent with the findings in the literature review. However, the tests required extensive time selecting, measuring, marking, and observing the yarding of logs, which for the most part were unchanged in the yarding process. The percentage of individual logs damaged was relatively low: only sixteen logs out of nearly seven hundred (see Table 6). The amount of work involved in the detailed tests and the disruption of normal operations which unavoidably occurred, make it impractical to apply the pilot study methods on an operational basis. Because of the low levels of breakage found, however, it would be practical to focus attention on occurrences of individual log damage.

The results of the pilot study emphasized the need for a means of compensating for the effects of widely varying sample sizes. It was shown how a stabilized control chart would eliminate this problem.
Recommended quality control system:

These procedures involve the use of control charts as discussed in the literature review above. Control charts are a method which has been found to be effective in many industries and situations. Other quality control methods for analyzing a system were also discussed in the introduction above and should be used as appropriate.

The procedures suggested for controlling log damage under operational conditions consist of two major components:

- A checksheet for gathering information related to damage during yarding, and
- A control chart for attributes to summarize and monitor the log damage recorded on the checksheet.

These procedures are recommended as a means of overcoming two of the main problems identified in the pilot study; collecting sufficient data to begin solving the specific problems involved in improving value recovery, and monitoring and controlling operations on a current basis without costly and time consuming measurements of large numbers of logs. Checksheets are an effective means of collecting this information by providing space for recording large amounts of information in a systematic manner. Control charts for attributes are suited to the normal situation in harvesting operations in which the numbers of logs which are actually damaged are relatively small. Eliminating measurements of logs makes it feasible to examine the large
number of logs which is required to ensure that samples include a representative number of damaged logs.

Using attributes control charts also provides a means of control in the interim period while the development of methods of scaling and grading logs which reflect actual value loss potential is proceeding. When improved methods of scaling and grading are developed, they can be tested and incorporated into control systems to monitor actual value loss.

Other advantages of using control charts for attributes in the recommended manner are: Sample bias resulting from problems with marking and sampling will be eliminated. This is because all logs yarded during the observation period will be part of the sample. Unexamined logs will not be a problem with the recommended method. It will not be necessary to mark logs in advance of yarding, and therefore, problems with identifying and accounting for logs at the landing will be eliminated.

Conclusions:

In this thesis, quality control methods have been examined and field trials have been performed, with the objective of developing a quality control method to improve value recovery in yarding operations. The following conclusions have been derived:

- Control charts can be used to improve value recovery through monitoring of operations, assisting in the analysis of special causes of variation and providing feedback of results to workers and management.
• Estimates of value loss are approximately one percent for operations using current yarding systems in old growth stands on the west coast of Vancouver Island. This loss is consistent with losses estimated by others. Differences in results between systems could not be distinguished from random variation.

• The recommended approach for yarding operations is: Establish control using charts for attributes and check sheets to remove special causes of variation, then continue improvement of operations by reducing common variation.

• Savings from improving value recovery may be substantial. An improvement of ten percent in the estimated average value loss of one percent would result in an increase in revenue of $30,000 annually, for the typical woods operation discussed above. This should cover the cost of implementing the recommended system. Further benefits should be realized over time as continued improvement is achieved.

• Difficulties in scaling, grading and collecting data on initial log values need to be resolved. The current scaling system is designed to measure volume and grade for statutory purposes and does not measure variations in quality which do not effect statutory value. Grading rules followed for statutory grading of logs do not reflect the potential value recovery from converting logs to their highest value product and therefore value losses
in higher log value categories are likely to be substantially understated if based on statutory grades. Methods of data collection need to be developed which will make it possible to safely, efficiently, and accurately measure and grade logs before and after yarning.
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APPENDIX - MAPS

Map 1. Location map of Walbran Creek.

Map 2. Setting map showing areas yarded by each system.
MAP 1
WALBRAN CREEK
LOCATION MAP

NOT TO SCALE

VANCOUVER ISLAND
23 KM

WALBRAN CREEK
STUDY SITE
MAP 2
WALBRAN CREEK

OPENING: 15-4-C
AREA: 20.8 HA. (18.0 NET)
VOL/HA: 828 MS
SPECIES %: C: 65; H: 27; B: 8

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>AREA (HA.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRAPPLE</td>
<td>5</td>
</tr>
<tr>
<td>SKYLINE</td>
<td>4</td>
</tr>
<tr>
<td>HIGH LEAD</td>
<td>7</td>
</tr>
<tr>
<td>WIDE ROW</td>
<td>2</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
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