# J. W. Gottstein Memorial Trust Fund

The National Educational Trust of the Australian Forest Products Industries

GOTTSTEIN
TRUST

# THE APPLICATION OF MODERN METHODS TO LOG MEASUREMENT FOR THE PURPOSE OF DETERMINING QUANTITY

**STUART WEST**

2001 GOTTSTEIN FELLOWSHIP REPORT

## JOSEPH WILLIAM GOTTSTEIN MEMORIAL TRUST FUND

The Joseph William Gottstein Memorial Trust Fund was established in 1971 as a national educational Trust for the benefit of Australia's forest products industries. The purpose of the fund is *"to create opportunities for selected persons to acquire knowledge which will promote the interests of Australian industries which use forest products for the production of sawn timber, plywood, composite wood, pulp and paper and similar derived products."*

Bill Gottstein was an outstanding forest products research scientist working with the Division of Forest Products of the Commonwealth Scientific Industrial Research Organization (CSIRO) when tragically he was killed in 1971 photographing a tree-felling operation in New Guinea. He was held in such high esteem by the industry that he had assisted for many years that substantial financial support to establish an Educational Trust Fund to perpetuate his name was promptly forthcoming.

The Trust's major forms of activity are,

1. Fellowships and Awards - each year applications are invited from eligible candidates to submit a study programme in an area considered of benefit to the Australian forestry and forest industries. Study tours undertaken by Fellows have usually been to overseas countries but several have been within Australia. Fellows are obliged to submit reports on completion of their programme. These are then distributed to industry if appropriate. Skill Advancement Awards recognise the potential of persons working in the industry to improve their work skills and so advance their career prospects. It takes the form of a monetary grant.

2. Seminars - the information gained by Fellows is often best disseminated by seminars as well as through the written reports.

3. Wood Science Courses - at approximately two yearly intervals the Trust organises a week-long intensive course in wood science for executives and consultants in the Australian forest industries.

4. Study Tours - industry group study tours are arranged periodically and have been well supported.

Further information may be obtained by writing to,

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J.W. Gottstein Memorial Trust Fund,
Private Bag 10,
Clayton South, VIC 3169, Australia

## ACKNOWLEDGEMENTS

I am indebted to the Trustees of the Joseph William Gottstein Memorial Trust Fund for giving me the opportunity to undertake this study and for the assistance that they provided.

I would also like to acknowledge my employer ForestrySA, for their interest and support in this project.

I am extremely grateful for the cooperation, assistance and hospitality extended to me by all of the organizations visited as part of this Fellowship.

## STUART WEST

Stuart West has a Bachelors Degree in Science (Forestry) from the Australian National University in 1990. After graduation Stuart began work for the Woods and Forests Department in Mount Gambier, South Australia in the Forest Resources Section. The primary function of this Section was forest inventory, growth modelling and yield prediction.

In 1997 Stuart was employed as the Marketing Development Manager within the Department that was renamed the Forestry Group of the Department for Primary Industries. Here Stuart's roles included strategic planning and management of the organization's Quality Accreditation program. During this time the Forestry Group was corporatised and renamed ForestrySA.

Stuart lectured the Forest Mensuration course of the Forest Technology Certificate at the South East Institute of TAFE from 1995 to 1997 in Mount Gambier.

In 1999 Stuart moved to the South East Harvesting Section of the Plantation Products Group as the Logging Planning Manager. In this position Stuart's primary function was the operational management of the harvesting and transportation contracts in the South East of South Australia. Stuart remains in this position today.

Stuart is currently in his third consecutive term as Chairman of the Logging Investigation and Training Association (LITA). LITA is funded and managed from the South East Regional industry to improve efficiency, productivity and safety of operations within the regional industry.

## INDEX

# 1 EXECUTIVE SUMMARY

Log measurement for the purpose of determining quantity is performed to identify products along the supply chain from forest owner to processing. Measurement commonly occurs wherever there is a change in custodian. Different organizations in Canada, the United States of America, Finland and Sweden address the issue of collecting appropriate information using methods suitable to Australian forestry.

The type of systems and technologies used in these countries varies dependent upon whether the forest is privately owned or owned by the government. Systems are also influenced by whether the customer is part of the same organization, or the logs are sold in the market place. The level of control exercised by the government in each of these countries varies greatly, depending on policy regarding monitoring harvesting levels. This can affect the level of information collected, recorded and reported.

Log value has a significant effect on measuring systems, especially if there is large variation for similar products in the same market. Accurate systems to obtain measurement information are often related to log grading functions as well as quantity determination. Depending upon the description of products being sold, it is common for the same logs to be measured on up to five separate occasions, often using different techniques.

Log measurement systems that identify individual logs provide the highest level of functionality and information tracking along the supply chain. However this type of system also generally has the highest cost. This high level of information is not necessarily required by all supply systems, and a suitable compromise for cost and detailed information is identifying measurement information by loads, not logs. This type of system is only successful if it is implemented with a system to segregate all loads, a process that is performed with ease in Sweden and Finland.

A number of different techniques and systems are described with comments on their suitability to Australian forestry.

# 2 INTRODUCTION

Log measuring, or scaling, is the process of obtaining the physical dimensions of a log to calculate a unit of measure. The generally accepted measurement unit in the forest industry around the world is volume. This is calculated from a measure of the log length, and the nominal log diameter.

Equipment manufacturers, forest owners and processing facilities continually investigate improvements to log measurement.

Log measurement for the purpose of identifying quantity is performed to identify products along the supply chain. It commonly occurs wherever there is a change in custodian. The measurement information is used for payment in relation to processes such as harvesting and delivery to the purchaser's processing plant, payment to the forest owner, and grading and any other handling of the log. It is common for the same logs to be measured on up to five separate occasions, often using different techniques.

- Modern mechanical harvesting equipment provide some form of inbuilt measurement facility and can often record production.

- Harvesting operations generally employ a number of workers to assist in the final delivery of products. These workers are paid according to production (piece-work rates), with each not necessarily responsible for handling the total production. This creates a requirement for the harvesting manager to quantify different components of the total production according to the processes it undergoes.

- The forest owner will usually independently quantify the production for a defined forest area. This is usually performed on the forest owner's employees or an independent group.

- Delivery to the processing customer involves reconciliation to confirm that the delivered volume matches the volume claimed to be supplied by the forest owner.

- If the product is delivered to a preliminary sorting or distribution centre, then it will be measured at least on entry if not also on exit from the centre.

All of these processes require a high level of accuracy, and utilize their available equipment and technology to perform the same function. The value attributable to this measurement information is usually the major cost (or revenue) item for each custodian.

As the demand for forest products increases, and forest owners attempt to maximise value from reducing average log sizes, the use of more efficient log measurement technologies will improve cost effectiveness. A parcel of smaller logs of lower value often requires increased measurement cost than the same volume of larger logs. They will take longer to measure and will be more physically challenging for most measurement techniques.

A recently emerging purpose for this information is to identify log quantity information at different positions along the supply chain. This will allow specific log information to be tracked back to the plantation of origin. Any future requirement for green labelling of forest products will contribute to the need for this type of information.

It is uncommon and difficult for today's forest owner to obtain and track log volume information from the delivery customer back to the forest, even though the processing industry is demanding a greater level of stand information prior to harvesting. This information will have great advantages to both the forest owner and to the processing industry, and any improvements to quantity information is keenly sought by both sides of the log sale process.

Different custodians along the supply chain use different measurement units, thus creating a requirement for conversion or remeasurement of the same quantity.

Forest owners traditionally model growth and predict production in volume, but measure actual production of some products (timber) in weight and then convert back to volume. Pulp is usually sold by weight.

The harvesting and transport industry operates in between the forest grower and delivery to the purchaser, and is integral to the buying and selling agreement. In Australia this industry uses as its basis a weight system, as opposed to the volume based system used by the supplier and many purchasers. Weight is measured either at weighbridges or by using onboard scales, but frequently this unit must be converted to volume for payment from the buyer or seller.

Thus, the use of volume as a measure of quantity for forest products is widely accepted and understood as a general industry standard. Any system that deviates from volume would be subject to critical review and conflict with the industry culture.

# 3 OBJECTIVES

I have used this JW Gottstein Fellowship to investigate and understand the methods and technologies for timber measurement currently being used in regions that have a reputation for leading forest practices. I investigated the application of modern methods to log measurement for the purpose of determining quantity and hence and value. Systems were observed in the Canadian provinces of British Columbia, Quebec and Ottawa, the United States of America States of Washington and Oregon, and in Finland and Sweden in the month of May 2001.

My experience and interest is primarily in plantation forestry, however the general principle of log measurement to determine quantity is relevant to all production forestry. The organizations that I visited were associated with intensive production forestry and quantity scaling was the primary goal of measurement.

The systems observed included harvesting operations and sorting/ processing centres for both cut-to-length and long-log operations, measurement systems at sawmills and merchandising yards. Visits were made to system developers and research institutions where modern technologies were being developed or trialled to replace existing methods of log measurement.

My investigations also included modern methods for the collection and tracking of information along the supply chain from the forest to processing facilities.

Adoption of improved technologies or practices for log measurement may initially require investment in both time and capital. However it should be possible to produce quantity measurements at reduced cost in the long term that is accepted as a consistent form to the benefit of the forest industry.

# 4 Australian Log Measurement

Australian practices for log measurement are generally modified from the historical processes developed by the established private forestry companies and forest services in the twentieth century. Commonly the forest owner and the purchaser were different parts of the same organization, and log measurement was only used for internal transfers. Today most businesses have a core business focus, and log measurement is the basis of calculations to invoice or make payments to external customers.

Log sale agreements vary in the method specified for quantity determination. These range from sales based on weight or sample measurement and weight conversion to full manual measurement and grading of high value logs.

Currently in Australia almost all sawlogs are sold by volume. Sample log scaling is used to convert to volume by size assortment when weight is the primary unit of quantity information. Manual scaling methods estimate log volume by multiplying a diameter measurement by the length. Log volume estimation techniques range in accuracy from sample measurements based on estimates and experience, to complete (100%) scaling using a wide array of formulas based on measurements taken a various points along the log. At static processing locations it is now common for multi-axis scanners to measure at sub-centimetre intervals along the entire log. This is now possible along a number of axis to produce extremely accurate estimates of log volume.

The result of using a range of measurement systems is inconsistent and incomparable quantities. Any two (different) systems used to identify the quantity of a specific bundle of logs will produce results with enough variation to create confusion as to the true quantity. This confusion ultimately progresses into the negotiations between the purchaser and the seller, and agreements need to include lengthy procedures to address disagreements in quantity measurements.

If fewer procedures were generally accepted within the industry, this would reduce confusion in the supply chain, and improve the quantity identification and sales process for this globally competitive industry.

Ultimately the forest owner and customer will benefit from consistent and repeatable information irrespective of the sales agreement or measurement location. The same bundle of logs measured in a number of locations should produce the same measurement information.

Information collected closer to the stump in a timely fashion will improve supply and delivery optimisation, and assist stock management at processing facilities. This will provide opportunities for decisions earlier in the supply process and improve the audit processes for everyone in the supply chain.

There is a need to develop log measurement technologies in Australia so that we can interest people in better matching log supply to demand. Currently there is no standard approach to log measurement in Australia. A suitable alternative could improve this process for all of Australia, and reduce confusion and scaling costs, while increasing delivery control

It is likely that segments of the forest industry in Australia can take advantage of cheaper automation to replace manual log measurement, and make use of more efficient technologies. This will be an important issue as wood availability reduces along with average log size.

The forestry culture in Australia makes extensive use of the government weigh bridge infrastructure. This culture is reinforced by the general road transport industry of Australia, and has its own regulations and compliance enforcement. Therefore it would be expected that any Australian log measurement system that incorporates the use of weighbridges is likely to be generally and readily accepted.

The simplest system of log measurement would make the basis for payment of everyone in the supply chain (forest owner, harvesting, haulage and purchaser) a single agreed measurement (with validation).

## 5 Harvesting systems

The systems and operations observed were both Cut-to-Length (CTL) systems and long-log harvesting. Some of the operations included a combination of these systems, including overhead cable harvesting of long and short length logs. The log measurement techniques varied with the type of system, however the general approach to measurement is consistent across all types of system.

Conventional CTL systems involve mechanical harvesters processing trees to defined length and diameter specifications, subject to operator intervention (generally for quality). Tree felling and processing to these specifications occurs within the forest, where the final product is extracted to the forest edge, sorted and delivered to the product destination.

Unlike CTL systems, long-log harvesting (either manual falling or mechanized log harvesters) involves the extraction of the whole tree or tree sections to the forest edge. Here the log length is sorted and loaded for transport to a central processing plant where the infrastructure is used to perform the cutting to length (Figure 1).

In the harvesting operations of eastern and central Canada, long-log harvesting systems are on the decline and represent less than half of the total harvest. However the interior of British Columbia and the Prairie Provinces are dominated by long-log harvesting. Harvesting in mountainous coastal British Columbia is dominated by cable yarding which employs long log extraction.

Figure 1. Long-log system, Vancouver Island, British Columbia.

Oversize off-highway trucks are frequently used in Quebec, Alberta and British Columbia, where most of the logs are hauled on private roads. On the coast of British Columbia, the majority of operations have a marine link in their transportation phase.

The northeastern states of the United States use both cut-to-length and long-log operations, with the latter more common due to log size. As with the Canadian provinces, great use of log processing/ merchandising yards is made for these long log operations. Delivery to the purchaser is generally in short CTL form.

Oregon State University uses a number of different systems (and trial new system types) in their 7000-hectare research forests. All systems produce cut-to-length long log in the forest. These logs are delivered to the sawmill in up to forty feet length, where the sawmill then cut to any length to suit their requirements.

In Finland and Sweden the harvesting systems are predominantly CTL, which reflects the relatively small log size and climate. The forest industry environment has a greater mechanised focus in these countries, which has developed along with the culture particular to these regions.

# 6 Log Measuring

Log sales commonly specify the supply of products within different diameter size classes, often with different prices for each class. Each of the regions visited have developed log measuring systems to match the level of information required by their industry. In almost every site visited this included identifying the supplier, either per log or per trailer load. In most cases it was possible to identify which contractor was responsible for a particular log, and the coupe where it came from. This appears to be a standard level of information around the world.

Log measuring is performed to satisfy government regulation in many of the countries visited, particularly when harvesting from government owned forest.

In British Columbia the Ministry of Forests (MoF) requires all logs from all forests – both private and crown - to be scaled (to government regulation) and reported. Scalers must be licensed. This allows the MoF to monitor the total cut for British Columbia, and is the basis of royalty payments to the MoF.

Different regions in Canada have different scaling requirements specified by the MoF. These mostly relate to species, grading and the assumptions regarding defects. In British Columbia there are two different types of log scaling: Coastal scaling and Interior scaling, applicable to the two regions within the Province. The Coastal system has many more grades than the Interior system, and logs are scaled according to which region they are harvested from. For large scaling companies operating throughout this Province, often their scalers are required to have both licenses.

At the TimberWest sort yard on Vancouver Island logs are delivered in variable length from five to fifteen meters. All logs are laid out in the yard and sorted by species, bucked, graded and then scaled (Figure 2). Every log cut is measured and recorded, including pulp.

Starker Forests in Corvallis Oregon have their logs scaled by a third party scaling company (Thompson Timber Co.) according to Columbia River Bureau Scaling procedures. All purchase agreements from this log yard specify this procedure as the measurement method used to determine the sales volume, which is the volume of a cylinder using small end diameter (similar to JAS).

Weyerhaeuser in Oregon supply their log yard from their privately owned forest. Therefore scaling is performed to satisfy internal purposes only. Sales from this log yard are based on scaling recorded upon entry to the log yard, or based on scaling performed by the purchaser at the delivery sawmill. Either of these methods can be agreed during the sales process, and the cost negotiated into the purchase price.

Figure 2. Logs sorted by grade (Grade 2), Oregon.

The Swedish timber measurement law states that the measurement of timber must be carried out according to regulations issued by the National Board of Forestry. This law was requested by the Forest Owner's Association to secure the fair, uniform and impartial measurement of timber. All measurement of sawlogs and pulpwood in Sweden is performed according to the same regulations, resulting in uniform measurement information.

The Timber Measurement Association was established in 1892 and measures virtually all saw log deliveries in Sweden. The seller and the purchaser cooperate to ensure impartial measurement, and the Association ensures that the measurement is performed in a consistent manner. The measurers are employed by the Association and are independent of the seller and the purchaser.

Log measurement in Sweden has progressed from measurement in the forest to measurement at the sawmill. This has increased measurement capacity and reduced cost, simplified handling in the forest, and improved delivery to match demand.

The Timber Measuring Association mechanically scales all logs using an optical scanner located at the in-feed deck at the sawmill (Figure 3). While the logs are automatically scanned for length and diameter, the operator assigns a log class to each log based on quality, and identifies the bark type. All of this information is then used to determine the overall grade of the log, and hence value.


Figure 3.  Timber Measuring Association measuring station, Sweden.

Large scale log measuring occurs at both log-processing centres for long-log operations, and at the forest edge for cut-to-length systems.  Both types of harvesting systems also involve log measurement at the sawmill.

### *6.1 Multiple Scaling*

Some forest owners/ suppliers harvest and measure logs, then sort by grade and offer specific volumes for sale.  In countries where there are a number of different scaling systems in use, the scaling system specified in the sales contract may be different from that used to collect the data.  This situation occurs at the TimberWest sort yard on Vancouver Island where logs are sold to different Canadian provinces.  Where this occurs the cost of remeasurement is negotiated into the sales price, and the logs are either rescaled by the purchaser or the seller.  If the scaling is required to satisfy MoF regulation then the purchaser is able to rescale and satisfy the regulations.

Harvesting operations in the United States, such as Weyerhaeuser's operation in Longview Oregon that supply their log yards from privately owned forest are only required to scale logs for internal purposes.  Sawlogs that are purchased from Crown forest are scaled by Government scalers at a Crown weigh bridge, and then rescaled by the purchaser upon entry to their log yard.

Any saw logs which Weyerhaeuser sell domestically from their Longview log yard may either be sold based on the scaling already recorded upon entry to the log yard, or based on scaling done by the purchaser at the delivery sawmill. Either way the measurement is negotiated into the purchase price. If the purchaser is buying based on the purchaser's scale then Weyerhaeuser will compare the final sales volume with their scaled volume.

In Sweden and Finland, logs are first measured during harvesting by the harvesting machine. The same logs are measured by the customer or an external body such as the Timber Measurement Association upon delivery to the sawmill. Generally only the information produced at the sawmill is used as the basis for financial transactions.

The accuracy requirements of log measurement vary throughout the provinces and countries visited, and between purchaser and seller. Generally the measurement classes reflect the uniformity of the available logs, and the expected variation. Logs in Finland and Sweden are measured in one-centimetre classes. Operations visited in Canada and the United States measure using five centimetre classes.

The measurement information is obviously limited to the accuracy with which it is collected. All measurement techniques other than scanning require the remeasurement of logs if they are to be on-sold to a different customer or province that specifies a different classification. Numerous circumstances were observed where this was the case, and the cost of remeasurement into the new classes was accepted as part of normal business.

### *6.2 Scaling Qualifications*

In Canada all scalers must hold a log-scaling license. In order to get a log-scaling license scalers must pass a government licensing exam. The exam is a two-day exam, one day for the written exam and another for the practical exam. Log scaling courses are usually five months long full time evenings or weekends. Courses are relatively expensive and have a consistent pass rate of 30%. The success rate for first time students is closer to 15%.

Scalers working in the United States measuring logs from private forest for private consumption such as Weyerhaeuser at their Longview Oregon sort yard are not required to be licensed. However these types of companies conduct periodic internal auditing of scalers. Scalers employed to measure logs from Crown forest, or logs from private forest to be sold on the domestic market in the United States, such as the Longview Fibre sort yard at Clatskanie in Oregon are required to be accredited to government regulations.

Employees of the measuring organizations in Finland and Sweden are not licensed, but are trained and monitored to measure according to government specifications. Because the information produced by these organizations is used as the basis for payment to all custodians involved in the supply, there is close scrutiny of the systems and procedures in place. Added control exists in these circumstances simply because the measurement occurs at the purchasers premises.

### *6.3 Who employs the scalers?*

Irrespective of who pays the cost of measurement, it is generally reflected in the purchase or tender price. All forest owners and processing organizations require their own measurement systems in situations where either the purchaser or the seller has the measurement responsibility. Each party uses this information either as the basis for invoicing and payment, or to validate the measurement information of the other party.

The system used in Sweden where the independent and impartial Timber Measurement Association is responsible for measurement is the simplest. The Timber Measurement Association employs the log scalers and provides the scaling service to the sawmills, which pay the measuring cost. The information provided by the Association is used to calculate all payments in the chain of custody, including harvesting contractors. Therefore although the overall cost is paid by the purchaser (sawmill) it is effectively negotiated into the purchase price. Here both the purchaser and the supplier are content with the measurement information. Anecdotal evidence from harvesting contractors suggests they would prefer to be paid based on the information that they produce. As small businesses and owner operators they are more trusting of the information that they are responsible for, as opposed to measurements produced by large organizations. However, these contractors still operate in the environment where they are paid using someone else’s measurements.

TimberWest in British Columbia pay their scalers on an hourly basis. This is a deliberate attempt to avoid inadvertently creating incentives for overestimating volume if scalers were paid based on production. Weyerhaeuser scalers measuring internally from their private forest are paid a weekly wage for the same reason. Weyerhaeuser allow purchasers the option to remeasure at their delivery location. Purchase price and additional measurement costs are negotiated into the sales agreement. Whichever measurement method the customer selects depends upon their confidence in the supplier. However there will always be some validation of the measurements if the customer accepts the information provided by the seller. In the United States the government employs scalers to measure from Crown forest to record royalty payments.

Oregon State University employ a third party scaling company to scale all sawlog from their forest, and the scaling occurs at the sawmill. The University pays for the scaling, but obviously considers this cost when negotiating the selling price.

At the Starker Forests log yard in Oregon the scalers are paid by the forest owner

(Starker) but contracted from an independent scaling company. These scalers are well paid and competition for employment is high, producing a high quality work force. These jobs are regarded as premium positions.

### *6.4 Log Scaling costs*

The cost of log scaling for all of the regions visited varied relative to the level of information that was recorded, and the infrastructure utilized at the scaling operation.

Log scaling in British Columbia is estimated to cost approximately CA$ .70c/m3 (A$ .65c) on average. Log scalers at the TimberWest sort yard on Vancouver Island are paid CA$ 25/hr. The total cost of running this sort yard is between CA$ 5 and CA$ 6/ m3 (A$ 4.50 to A$ 5.40), however the actual scaling and grading cost is only about CA$ .90c/m3 (A$ .80c), and the remainder is contributed to machinery lease costs and fuel, etc. This sort yard in particular has six large rubber tired loaders, and a very large static high lift crane. This TimberWest crew of ten scalers is able to scale up to 4500m3 per day as long as the supply is maintained. In British Columbia individual scalers can scale up to 700m3 per day.

Weyerhaeuser pay their log scalers US$ 42,000 per year for a conventional eight hour day at their Oregon log yard. This equates to US$ 23 per hour, and this is quite favourable when compared to the average ‘unskilled’ wage, which is US$ 11 per hour. There are two main species supplied to this log yard, of which Douglas Fir receives a premium of two and a half times the value of Hemlock. The responsibility placed on scaling in this system is reflected by the relatively high remuneration paid to the scalers.

Longview Fibre at Clatskanie operates their sort yard for approximately US$ 2.00 per m3. Longview estimate that only 5% of their total sort yard cost is attributable to actual scaling, and the remainder is associated with fixed sort yard costs. This large sort yard receives 2.6M m3 per year.

The log yard used by Starker Forests receives approximately 250,000 m3 of sawlog from their private forest resource. This log yard is owned and operated by a separate company – Thompson Timber Company, and Starker pay a fee for the use of these facilities. The high machinery level associated with shifting logs within the yard by excavator and loader result in high fixed costs for the yard, there are currently four tracked excavators operating in this log yard. This log yard has a high level of machinery operations, including grapple excavators to position each individual log for scaling. The scaling costs for this yard are US$ 4.00 per m3. This cost is quite high, however considering in involves applying bar codes to almost every log, and then removing these bar codes as the logs leave the yard, it produces a high level of accurate log information. To reduce the measurement costs for small, low value logs, logs under a specified diameter are not individually bar coded, but are identified by three or four tags per truckload. These logs are still individually scaled and recorded, but can not be traced back to individual log information once sorted.

The Timber Measurement Association in Sweden employs approximately eight hundred scalers, and measures at all sawmills for SEK$4 per m3 (A$ 1). However the Association operates from measuring stations that are provided, established and paid for by the sawmill owner. These measurement stations cost up to A$ 1 Million. Therefore this measurement cost is purely an operational cost that includes keying of the data, maintaining the database and preparing invoices. This relatively high cost remains acceptable and appropriate considering it is the only measurement performed, and is used as the basis for all payments in the chain of custody. This system produces highly accurate information commensurate with the costs to collect it. The Association employs 800 scalers for all of Sweden, and these scalers measure more than twenty one million cubic meters each year on two shifts.

### *6.5 Scaling Techniques*

All of the manual scaling systems observed in Canada and the United States used log rulers to determine diameter (Figure 4), and calculated the nominal diameter based on measurements on two axis.

Figure 4. Log scaler with log ruler, Vancouver Island, British Columbia.

For efficiency Longview Fibre at Clatskanie utilise three small stroke-delimbers to process (CTL) small whole tree lengths. These logs are graded by the delimber operator and sorted accordingly. These small logs are not manually scaled because their value does not warrant it. However higher value whole tree lengths at this site are manually bucked, and 'walked over' for scaling.

The University of British Columbia are currently investigating using harvesting head measurements to replace manual measurements. However because the Canadian culture is based on manual scaling, and the Ministry of Forests (MoF) relies on this information for royalty payments, the shift to this technology is slow, and not likely in the near future. This is especially so in British Columbia where the MoF sets the gross annual royalty at the beginning of the year, and the purchasers of the forest products must manage within this limit.

The third party scaling company employed by Oregon State University use a retractable builders tape to measure length and diameter of the large end, and use taper functions to estimate the small end diameter. This reduced accuracy reflects the research focus of the forest owner, where the research forest is not the core business of the university, and the purpose is as much education as it is revenue recovery. Similarly the Weyerhaeuser Longview log yard use taper functions to calculate small end diameter.

In Finland and Sweden where the scaling occurs at the sawmill using optical scanners on a log deck, the length and diameter calculation is mechanized. Only the function of classifying the log quality, and identifying the bark type and characteristics is performed by the scanner operator. Once again this technique is the most repeatable, especially with multi axis scanners.

The Timber Measurement Association measures logs for length, diameter and bark type (which relates to thickness). Logs are also assessed for quality to match certain end use requirements, and are classified into one of four or five classes depending upon species. This quality assessment is based on visible characteristics on the surface of the log (ring width, knots and faults) and refers to the whole log. Procedures for deductions of length are well defined by the regulations, and understood by the seller and the purchaser.

### *6.6 Auditing of Scaling*

Where scaling is the basis for royalty payments to the government it is common for the government to regulate the conditions for auditing of all scaling operations. In Canada, the MoF stipulates that at any point in time, all log yards, or any place where scaling is performed must have at least one truck load of logs laid out available for a validation scale, performed by scalers from the MoF. The logs must be audited in exactly the same position as they were originally measured. They must not have been rolled or interfered with in any manner so that the measurements will be consistent. The frequency of auditing is generally daily for a log yard capable of measuring up to 20,000 m3 per week from crown forest.

Canada was observed to have intense auditing and monitoring regulations which were complimented with associated severe penalties for incorrect grading. As a result this system produces a scaling industry that is effectively self-regulated. For log yards that are only supplied by private forest, the MoF has a reduced audit intensity, as the only purpose is to monitor production. The Weyerhaeuser log yard on Vancouver Island scales 250,000 m3 per year from private forest only. MoF auditing here is approximately once per week, however one load must still always be available for MoF measurement.

Because the MoF has a strict auditing procedure for log scaling, the purchaser has confidence that the scaled volume is accurate. All that is required when purchasing a log boom or grade is some validation of the total delivery, generally this involves confirming the correct number of logs or bundles are supplied.

Starker Forests contract a third party log scaling company to perform measurement of their logs. This contract includes confirmation of scaling accuracy, with the responsibility remaining with the contracted scaling company. While the scaling service is provided by a separate contractor, Starker employees still work within the log yard monitoring the grading and sorting into log decks to be offered for sale. Quality is monitored by Starker Forests to ensure consistency within each sorted grade.

The Timber Measurement Association records all measurement information electronically, and individual log measurements can be obtained. The Timber Measurement Association is responsible for processing this information, and forwarding invoices that summarise quantity, quality and value to the purchaser, and copies to the supplier. The Timber Measurement Association performs regular internal audits, and performs remeasurement of specified volumes upon request of the purchaser or supplier. Internal audits and remeasurement requests are clearly documented.

### *6.7 Sample Scaling*

In all of the regions visited complete measurement was performed on most saw log operations and was easily justified due to the value of the products. For lower value products, the cost of measurement was reduced to align with the product value at most operations.

At Weyerhaeuser's Longview operation the procedure for low value pulp is different to that for saw log. Pulp is sample scaled at 10% for length and large end diameter, and the small end diameter is estimated using a taper function. Although this pulp is sold by weight scaling remains necessary for logs purchased from the crown because the royalty to the government is calculated using volume! Sample scaling is the most effective method to satisfy the crown.

This process could be simplified if the government calculated its pulp royalty using weight. The Timber Measurement Association of Sweden operate with similar conditions for pulpwood which is sample measured due to the low piece size and high volume of deliveries.

The scaling information collected at Weyerhaeuser's Longview log yard is forwarded to both the sawmill and the forest management inventory group.
Transport operators here are paid on an hourly rate. This eliminates the need to weigh trucks, or for weight to volume conversions, although all trucks are fitted with on-board scales to conform to vehicle mass regulations. Pulp logs are weighed at the pulp mill, and harvesting is paid by weight.

In the Canadian provinces of Newfoundland and Quebec the cold climate produces average tree size ranging from 0.1 m3 to 1 m3 per tree. In such environments sample scaling is the only effective method to determine measurement volumes other than weight. Here all sales are based on the volume from samples. Sampling occurs at one load per day for each coupe. Variation in value in these regions is due to grading by quality, and generally not measurement discrepancies, as there is only small variation in log sizes. This is typified by harvesting contractors in Quebec purchasing new modern Cut-to-Length harvesting machines without diameter measurement systems. This is to reduce the purchase cost, but generally only by less than 10%. Where the average tree size is 0.1 m3, the operator distinguishes between products by quality rather than size.

In Canada where the mass-volume conversion factors for sample scaling are defined by the government on a yearly basis, weight to volume conversion is the predominant method of measurement from government owned forest. If a purchaser is not confident in the conversion factor, they are able to scale 100% of logs as an alternative. This converted volume information is then also used to pay contractors as well as the forest owner. The expense of this alternative usually contributes to use of the government conversion factors.

### *6.8 Scaling Without Identifying Logs*

Log measurement systems vary in the level of detail that is stored. Although all of the systems measure individual logs, it is not common for this information to be able to be retrieved and traced back to individual logs. The only information applied either to sample logs, or complete logs for smaller log yards, or higher value logs, is a hammer stamp identifying the forest and harvester code.

At their Longview Oregon log yard Weyerhaeuser scale 100% of sawlog. Logs are unloaded, scaled (recorded on hand held computers) and then sorted to a log yard deck that is physically 'closed off' by steel rails once at a defined level. This system relies on strict log yard management. Weyerhaeuser here are harvesting from their own forest and either supplying their own sawmill, or exporting higher value products. Log yard decks are ‘opened’ as they are required by the sawmill or after sale, and the gross volume within each deck is available from the scaling summary. This system is well managed at Longview because there is a very large log yard area available to layout logs for scaling, sorting and grading. This system of scaling without recording any information on the logs is suitable for the purposes of the owner. Longview Fibre at Clatskanie use the same scaling system for their sawlog, and their pulp is delivered straight to the pulp mill using weight based measurements.

Oregon State University manage their 7000-hectare research forests without recording any log specific information. Here all pulp is weighed only at the point of delivery, and all sawlog is 100 % scaled by a third party scaling company at the sawmill. Logs are cut to long length and graded and sorted in the forest, and delivered as long length (generally 40 feet). The harvesting operation applies a specific hammer stamp to a small number of logs per load for identification. The scaling at the sawmill is performed on these long lengths, after which the logs are cut to any length required by the customer. Every load of logs has an accompanying haulage note carried by the truck, and the number from this note is entered onto a hand held computer at the time of scaling.

The University sells logs to three or four mills from the one coupe, and sales volumes are estimated based on cruise inventory. The actual price paid for forest products is the scaled volume recorded at the sawmill. Because the total forest owned by the University, and also the coupe size, is relatively small, tracking loads of logs in this system is relatively simple to monitor. However this system would be far less suitable to a large forest owner where tracking would not be possible on a much larger scale, and busier operations.

Log scaling in Finland and Sweden performed by scanners in the sawmill does not involve identifying any information on individual logs. However, all loads must have some logs clearly marked to identify the forest and contractor. This is commonly done by spray painting or using stamp hammer marks on approximately fifteen percent of the logs (Figure 5). There are strict penalties if a load is stopped during transport and no logs have stamp identification. As with all successful systems, these penalties act as effective deterrents to improper behaviour. Anecdotal evidence suggested that drivers caught with loads that have no identification are permanently banned from log transport driving. In these countries this is an appropriate system because the sawmill purchases the logs directly from the forest owner, and then engages harvesting contractors to harvest and deliver the logs.

Figure 5. Approximately 15% of logs with hammer stamps, Sweden.

Where logs are unable to be unloaded directly onto the log in-feed deck of the sawmill, they are stored in the log yard with the last two logs positioned vertical to separate each load (Figure 6).

Figure 6. Loads separated by vertical logs, Sweden.

This system allows trucks to deliver loads from different origins, as long as the truck bays separate each different supplier. Practically a four bay truck could deliver logs from four different forest owners, and this can be easily accommodated by this system. It is the segregation of loads within this system at the log yard that provides the flexibility and practicality for this system to work successfully.

For logs unloaded into the log yard without being scanned, the haulage note number is painted onto the end of one or two logs from the load (Figure 7). This will be used to correspond to the information from the haulage note once it is keyed into the measurement database. Each haulage note is delivered by hand from the truck driver to the scanner operator while the truck is being unloaded. The in-feed deck loader operator then uses radio communication to identify when the first log from the new load is loaded, and reads off the corresponding haulage note number from the log end if the logs are supplied from the mill yard stockpile.

Figure 7. Haulage note stapled to one log per load, haulage number painted onto one log end, Sweden.

### *6.9 Identifying Logs with Supplier Marking*

Identifying logs by their place of origin provides only the most basic level of information. This is useful to a purchaser or log yard where logs are purchased and delivered from a number of different sources and/or owners.

The Weyerhaeuser log yard near Crofton on Vancouver Island uses a hammer stamp to identify the forest owner and harvesting operation by three key code (eg. IE4) for every log that is delivered to the yard. This medium sized log yard (250,000 m3/yr) manages this process very well with five scalers, but produces outgoing logs which contain no log scaling information marked on the log. As the logs are unloaded on delivery, one log per load has a stapled paper ticket with the coupe identification, truck number and hammer stamp. All loads are kept separate as they are unloaded. As each log in the load is scaled and graded (recorded by paint mark on log end), it is given the appropriate hammer stamp, and grouped by grade. All information is recorded on hand held computer. The stamping process is completed in a negligible amount of time compared with the time taken to grade and scale. The scalers wheel a trolley around the yard that contains a variety of stamps, and all of their other scaling equipment (Figure 8).

Figure 8. Log scalers' trolley full of hammer stamps & paint, British Columbia.

Log grades are bundled and dropped into a lake for storage, and like grade bundles are held in a log boom for sale. Total measurements for the bundles and the boom are available from scaling, and this information is advertised for sale. Most products from this log yard are sold on the open market. It is not possible to obtain any information for a specific log other than the hammer stamp detail.

Similarly TimberWest use hammer stamps for all logs to identify forest owner and the harvesting operation, but use pulpable paper bar codes to identify the bundle volume for low value logs. These paper tags are applied to a couple of logs per bundle. The bar codes are perforated with two parts, and one code is removed as the bundle is put into the river for storage. This enables low value bundles to be tracked back to a sort yard and a harvesting operation, however individual logs can not be tracked.

Longview Fibre at Clatskanie, Oregon also use hammer stamps to identify the contractor and the private Longview Fibre tree farm for each log.

There were no systems observed in Finland or Sweden where individual logs were completely identified. In Sweden the Timber Measurement Association is present at all sawmills, and already provides an accurate source of log volume information. As the sawmill purchases directly from the forest owner, there is no requirement for this information at the forest.

### *6.10 Identifying Scaling Information on the Log*

Recording log measurement information on the corresponding logs is very expensive, but provides the greatest ability to track individual logs along the supply chain. A number of operations apply a different recording system to the high value grades. This usually occurs where a variety of species and hence value are delivered. Added to the high cost of recording information on logs, it is common for company auditors to require bar codes or tags to be destroyed in the removal process, so that they can’t be reused.

At the TimberWest sort yard on Vancouver Island, all high grade logs have a pulpable paper bar code stapled to them, which corresponds to the scaling information. Here these high value species are resorted and regraded a second time to optimise value recovery. These individually labelled logs also contain original supplier information that is identified on one log per load as they are delivered to the sort yard, and then transferred to each log within the load. Although this supplier information is very general (forest owner and location), the operations are harvested by a single contractor. The contractors are then required to collect and maintain their own information at the coupe level.

This system does not supply specific information for coupes within these harvesting areas. These logs are generally offered for sale on the open market, and the market currently is not requesting information at the coupe level.

Weyerhaeuser at Vancouver Island operate a similar system. High grade (usually export) logs have a plastic bar code staple to the end of each log, which are then bundled. This bar code records detailed scaling information as well as supplier information and operation.

At their Longview Oregon log yard Weyerhaeuser scale 100% of sawlog. Logs are delivered with an accompanying load ticket for transport. The information is keyed to a tag that is stapled to one log per load at the entry to the log yard. The truckloads are unloaded and laid out immediately for scaling. As loads are scaled, the information is entered into the hand held computer, and applies to all logs within the load. All logs suitable for export have a bar code to identify diameter, length, species, grade, defect, quality and scaler (Figure 9). The pulpable paper bar codes are stapled to the logs during scaling, and recorded on hand held computers. This log yard exports 200,000m3 of premium sawlog to Japan in thirty shipments each year. Export logs are sorted by grade, and sold on average length and diameter.

Figure 9. Logs bar-coded during scaling, Oregon.

As export ships are loaded the bar codes are read by wand and the tags are removed to satisfy anti-contamination requirements.

As with other log export operations, the Longview Fibre export facility at Clatskanie Oregon uses bar codes to identify individual sawlogs. Logs are transported to the export yard as tree length, with a bar code applied in the field. After bucking and scaling in the export yard each log is given a bar code, and hammer stamped to identify the tree farm and harvesting contractor (figure 10). The person bucking the logs to confirm the minimum sort specification only checks logs for diameter. The logs are accurately measured for length and diameter by a separate scaler following bucking, and entered into a hand held computer.


Figure 10. Log bar-coding and hammer stamped after scaling, Oregon.

The Corvallis Oregon log yard used by Starker Forests is supplied with saw logs only. All logs are given a bar code as they are scaled and sorted after unloading, except for logs below a specified diameter, in which case only three or four logs per truckload are coded. All logs are scaled and recorded on a hand held computer, including their sort category, and which ‘deck’ they are sorted into for storage. After grading logs are taken by loader to a sort ‘deck’, where a grapple excavator stacks the logs for sale. Therefore even for ‘decks’ that contain only small diameter logs, a total log count is available, and information per log has been recorded, to produce a total volume for the deck. Once decks are ‘closed off’ the total volume is offered for sale. The large amount of log handling by machinery in this log yard is reflected by the high scaling costs paid by Starker Forests.

Logs are scanned as they leave the log yard after the sale of a ‘deck’. Any logs that are missing their bar code are remeasured and regraded and matched against any unaccounted logs from the original measurements. This process recovers virtually all logs with missing or damaged codes. For smaller log-size decks where only three or four logs per load are given bar codes, there is still a total log count. Logs from unknown decks are returned to decks with logs of the same grade and size, to match the total log count. These logs are of low value, so a small number of replacements to a log deck are acceptable to Starker Forests. Once these decks are closed off (usually 10,000$m^3$) they are offered on the open market for sale. The purchaser is required to pay in advance for the advertised volume, and adjustments are made after the delivered volume is confirmed from the bar codes removed as they exit from the log yard. Starker reconcile all delivered logs with all outgoing logs.

The system used by Starker Forests in Corvallis was one of the most impressive operations observed. It produces measurement information of high accuracy and has effective procedures to reconcile deliveries with sales. However it is also one of the most expensive facilities to operate.

### *6.11 Enforcement of Regulations*

One of the keys to successful operation of any of the systems observed is the enforcement of regulations and monitoring to confirm compliance. Systems that do not include individual log labelling have a higher requirement to validate custodianship along the supply chain.

Quebec, Canada has the most effective system to regulate the supply chain. Here every truckload must have a ‘bill of loading’. At the junction where every forest road meets a major road there is a locked letterbox. Once trucks are loaded and begin their journey they must stop and place a copy of their bill of loading in the letterbox that is on the road nearest their forest origin. The police have keys and can check these letterboxes at any time. Therefore if a truck has not got the appropriate bill of loading completed, or is ‘stealing’ loads, it is possible for the police to detect. Because this system is enforced by law, all contractors comply. Penalties are anecdotally described as tough, but not commonly known because the law is rarely broken. This system is successful because the culture in Quebec has developed along with this law, and it is accepted and understood as being fair.

# 7 Log Scaling Systems

There is currently a large range of technologies available in mechanised forestry equipment and at delivery location infrastructure that can be used for log measurement. However, despite the continual development of technology into forest harvesting systems, conventional systems that measure the quantity of harvested product currently use high levels of manual processes.

The systems used to quantify production vary between forest owners and indeed between product purchasers. Measurements are regularly duplicated by different custodians along the supply chain, often using different techniques or systems.

Logs in Finland and Sweden are very uniform and as a result are generally sorted into one-centimetre diameter classes. Optical scanners at the sawmill provide the most effective and efficient method of measuring for such a high level of sorting specification.

## *7.1 Manual Scaling*

Manual measurement of logs was observed at a number of operations. Generally the manual scaling procedure was only used in operations where the major function was grading, particularly in Canada and the United States. In these places the most important function was to correctly identify the grade for each log. At TimberWest's Crofton sort yard on Vancouver Island, the value of the logs was so high that they were scaled twice due to the large variation in value for different grades. In this type of environment, there is little additional time required to record the dimensions of the logs manually, often this process is required to perform the grading function anyway. Effectively the cost of manual scaling is negligible and compliments the existing grading functions. No operations were observed where manual measurement was performed without grading.

It is often difficult to match labour requirements and wood flow in manual measurement systems unless there is a large stock buffer between measurement and the processor.

It is difficult to produce repeatable measurements from manual systems. The cost effectiveness of such systems also diminishes for small logs and for low value logs. Where log specific information is recorded with the log, for example with bar codes, manual measurement can be implemented successfully. Once measurement information is aggregated and not recorded with individual logs, the problems with manual measurement become more obvious.

Manual measurement of long length logs (generally greater than 3.0 m) commonly involves measuring diameter at two axis of the end and using the average for each end. Where size classes are used (commonly up to five centimetre classes) if the two diameters are one class apart, then often the first occurrence per load is classed as the small size, then next occurrence as the large size, and so on. However for short logs (generally less than 3.0m) this type of system becomes time consuming and labour intensive. So often only one end of the log is measured, recognising the reduced taper in short logs.

### *7.2 Onboard Scaling During Harvesting*

Today the major harvesting equipment manufacturers offer increased levels of computerised onboard measurement control, in a “Windows” computing environment. Information including harvest volume control and reporting can be downloaded to a Personal Computer, or printed from within the cabin from small thermal printers mounted within the operators cabin.

Modern harvesting machines were observed in all of the regions visited, however they were only fully utilised in Finland and Sweden where cut-to-length processing is standard practice. In Canada and the United States the application of long-log operations defeats the purpose of measurement information produced by the harvesting machine.

In Finland and Sweden information is able to be transferred via mobile telephone between the harvest manager and the harvester operator. Preferred cutting pattern specifications can be remotely ‘uploaded’ to the onboard computer. The only assistance required from the machine operator in this process is to answer the mobile phone call.

In Australia this type of data transfer is limited in its availability. Unlike Finland and Sweden that have complete mobile phone coverage, the coverage in Australia is far less comprehensive, and especially limited within canopy enclosed forest conditions.

This type of ‘real time’ access to cutting schedules aboard harvesting machinery is appropriate in these countries where the forest owner sells his standing trees direct to a processing plant / sawmill. The sawmill then engages a contractor to harvest the forest and therefore has a closer association with the harvesting operations, and a closer level of control, which is generally utilised to complement mill stock levels. This is particularly important in Finland and Sweden where harvest coupes are completed within days (not weeks or months), but far less suitable in Australia where the forest owner is generally responsible for the harvesting operations.

Swedish sawmills maintain the harvest information for completed forests produced by the harvesting machine. This information is utilised as a library, and as future forest areas are purchased, they are compared to existing forest files to optimise their cutting pattern.

The technical knowledge requirement for harvesting machinery operators is more likely to be satisfied in Scandinavian countries where the general contractor size is only one or two machines, and commonly owner-operated. In this same environment the harvesting contractors generally only work for a single sawmill, and this contributes to the increased level of control that the sawmill projects to the harvesting operations.

The computer programs which control the measurement calculation function within harvesting heads are well advanced, and include functions such as of filtering diameter recording to allow for the operator 'flicking' the delimbing arms to assist processing.

Finland was the only country observed where the harvested volume is sold based on information produced by the harvesting machine. This is only possible where modern harvesting machinery is used, and has on-board calibration facilities.

In both Finland and Sweden however, the volume information produced by the harvesting machinery is used by the forest owner as the validation for the final volume determined after scanning at the sawmill. Commonly the forest owner is paid according to this volume from the harvester summary, however it is always corrected and the final amount paid according to the scanned volume from the sawmill. As would be expected, the purchaser is not likely to adjust payments to the forest owner if the harvester volume is greater than the sawmill scanned volume!

Currently in Sweden there are no penalties for discrepancies between the Timber Measurement Association measurement and harvesting machinery production information.

This system that produces measurement information during harvesting is appropriate where the forest owner sells his products directly to the sawmill, which is responsible for the harvesting operation. It provides a level of information to the forest owner at the point of change in custody. This over bark measurement still has implied variability because it has no allowance for bark type. If the harvester information identifies species for each log then a basic level of bark thickness can be implied, but not accurately.

One of the most important aspects of using harvesting machinery to determine volume is the calibration of the machines. One of the major manufacturers' computer control system (Timberjack) has a calibration system that randomly identifies logs used for calibration by the processing computer. The on-board computer identifies random logs after processing for the operator to physically measure using electronic callipers that are 'plugged in' to the on-board computer.

Standard practice in southern Sweden is for the harvester operator to staple a printed summary ('stem file') of the calibration log to each log used for calibration.

The forest owner is then able to independently validate the calibration of the harvester. This summary contains basic log measurement information including the diameter at corresponding lengths along the log.

As the identification of logs used for calibration is random, and recorded as part of the volume report, the contractor must continually monitor the accuracy of the machine. He must ensure that all logs are harvested appropriately to maintain the agreed level of calibration. In Sweden this level is currently ninety five percent. In Finland the forest owner has the calibration audit responsibility, and at any time is able to inspect the calibration of a harvesting machine in his forest.

The on-board computer that controls the harvesting head information of modern machines is also integrated with the engine management system. In addition to monitoring specific log specifications, the harvesting manager is also able to monitor production time, and is able to report on 'downtime' greater than a specified period (eg. Fifty minutes). In Finland and Sweden this information is used as an additional verification of productivity.

In Sweden it is common for the large sawmilling companies to own and operate a small number of harvesting machines. This enables them to accurately identify the costs associated to the harvesting operations, and hence negotiate tough contract prices. The general feeling from harvesting contractors that were visited in Sweden is that since the economic downturn in the early 1990's, the current economic environment is not conducive to harvesting contracting.

In Finland and Sweden the small coupe sizes and the cold climate permits the completion of harvesting prior to sale of a coupe. Where this occurs, it is suitable for the forest owner to use the harvester reports to identify and describe the volume for sale. This is the most detailed information which the forest owner has access to, and is generally more accurate than pre-harvest cruise estimates, and is collected without cost. In Australia it is not common for coupe volumes to be completely harvested prior to being offered for sale. Again this is due to degradation in quality in higher temperatures, and large coupe sizes. As a result using this type of information is not generally appropriate in Australian conditions.

Mechanised harvesting systems have been in use in Finland since the 1970's. Many of these systems are developed in Scandinavia, and this is reflected in the local support and maintenance of such systems. For this reason there is a strong culture favouring these processes and the associated trust in the systems.

Although the harvesting industry in Finland and Sweden is well developed, there are still occurrences of harvesting contractors with modern machinery that is not used to capacity. A number of major harvesting manufacturers had evidence that 'dummy' parameters entered into the onboard computers by the manufacturer at time of delivery remained unchanged in a number of machines up to three years later. Clearly not all contractors in this environment are adequately trained or skilled to provide accurate volume information from their machines.

Within the Australian culture, it is often difficult for harvesting contractors in find operators who are skilled in harvester operation and technically familiar with computers. This probably requires an evolution of highly trained operators. For this type of information to be utilised in Australia there would need to be strictly defined procedures to accommodate breakdowns or interruptions to harvester information. Currently operational pressures require the operator to continue operating when the software malfunctions or experiences a break down, estimated to be up to 20% with some new machines. The measurement information from Australian species would also require development, as the uniformity of logs is far less than the Scandinavian conditions.

SkogForsk in Sweden performed an assessment of six of the most popular harvesting machines in the market in 1996. Although the control systems have developed to far greater levels today, these machines still make up a reasonable proportion of the current harvesting market in Australia. The results of this assessment of these machines (that were new at the time) are far from impressive. All of the computer-controlled systems observed could only produce diameter results of within four millimetres (outside bark) for less than 70% of the logs.

### *7.3 Optical Scanners*

Currently the most accurate and repeatable log measurement information produced within the forest industry is generated from optical scanners. Detailed information is available from modern scanners, and is easily manipulated into calculations for quantity determination. These systems are able to take into consideration local variations in measurement characteristics for branch stubs, defects, etc.

Sweden was observed to have the greatest utilization of optical scanners within log measurement systems. Here the Timber Measurement Association scale by scanning logs with bark on, sort into classes (usually one or two centimetre classes) and then store in the log yard for subsequent entry to the sawmill. When required in the sawmill the logs are debarked and passed through a different scanner to optimise the cutting pattern. Generally the scanner used for identifying the cutting pattern is of a much poorer quality and standard (and hence cheaper). This is because there is only minor variation of logs within each (one centimetre) log class, and the scanner is usually only required to identify whether to cut four or eight boards from the 'wings'. It is common for a sawmill in Sweden to use fifty log classes.

The Association has investigated using the same scanner for both log measurement and in-feed into the sawmill. However the requirement for the sawmill in-feed scanner to be positioned after the debarker does not suit the scalers who must grade on appearance, and identify species based on bark type characteristics.

A system where log measurement occurs at the delivery location relies heavily on the ability to identify and keep separate all loads from all coupes. This is especially important in Sweden and Finland where the forests are commonly small family-enterprise forest holding, and harvesters shift coups frequently. The systems observed in Finland and Sweden manage these requirements effortlessly (See page 23) using large Caterpillar 955 loaders. If logs were individually labelled or identified then this would not be necessary.

The key to the success in these systems is the ability to keep loads separate in the log yard, and onto the in-feed deck of the measuring scanner. Generally logs are unloaded directly to the in-feed deck and scanned immediately. Where this is not possible the logs are stored in the log yard and the haulage note number is painted onto the end of one or two logs from the load. This will be used to correspond to the information from the haulage note once it is keyed into the measurement database. Each haulage note is delivered by hand from the truck driver to the scanner operator while the truck is being unloaded. The in-feed deck loader operator then uses radio communication to identify when the first log from the new load is loaded, and reads off the corresponding haulage note number from the log end if the logs are supplied from the mill yard stockpile.

The optical scanners range from relatively simple multi-axis curtain beam scanners, to modern three-dimensional laser scanners in newly built sawmills. The scanner operator, who is an Association measurer is referred to as a scaler, however their function also includes the important classification of logs by bark type and species.

The Association is also responsible for invoicing to the purchaser. The central billing agency has a copy of all sales agreements, and calculates all payments all contract payments. Measurement information is validated against the haulage notes that are keyed over-night, and daily volume information is available the next morning.

Optical scanners have the ability to be calibrated at any required frequency (per shift or daily) (Figure 11). It would be possible, but time consuming to calibrate per load. In Sweden the Association is responsible for calibration of the measuring equipment. However processing facilities that are independently quality certified would have the ability to satisfy most audit requirements.

Figure 11. Calibration of optical scanner, Sweden.

Systems that rely on quantity information derived by the customer for invoicing and harvesting payments give control of the timing of payments to the discretion of the purchaser. This is obviously not a problem in Sweden, and should be simple to overcome in documented sales agreements. There is some additional log yard management required by the purchase to ensure that the first loads in to the log yard are not the last to be processed. In today's environment where monthly payments are common this is important to the cash flow of all custodians in the supply chain.

# 8 New technologies

### *8.1 Digital pellets*

SkogForsk in Skelleftea have researched into reusable digital pellets that are inserted into logs during harvesting. The pellets contain recorded log data that is coded during the harvesting process, and travels with each log. A signal receiver could then obtain this information at any point in the supply chain. This research has identified a number of factors that will inhibit commercial implementation. These include the individual cost of each transmitter (currently A$ .30c each) and difficulty in receiving this information from within the logs. There is a concern that the transmitters will interfere with the processing environment within the sawmills.

This technology is a highly technical application of a bar code system. In this system the log information travels with each log, and not in a corresponding database. As with bar code systems, any system that individually identifies logs has a high cost structure. This system in particular is quite complex, and relies on a number of operations that may be subject to interference, starting with the insertion of the transmitters into the log, and finishing with the extraction of the transmitters prior to processing.

### *8.2 Laser-Imaging Camera*

FERIC and the National Research Council (NRC) in Canada developed a system using a BIRIS laser-imaging camera mounted on a boom-stroke delimbing machine to view and record stem profiles during processing. This system was flawed by the physical conditions of the forest processing environment, specifically vibration and dust that effected this delicate and finely tuned equipment. Further problems occurred when the machine would generally process more than one stem per pass, and the recorded volume could not be related back to each stem. Here the alternative is to reduce productivity to process single stems only, however it was not considered acceptable to further develop a system that reduced current productivity.

This same laser-imaging technology was developed to measure log stockpile sizes within log yards. Laser Range finders are used to record dimensions and estimations based on void models for gaps between logs are applied to calculate the volume. This system is currently in use in some sawmills in Canada, where the information is primarily used to monitor log yard stockpiles and stock-take. The information is not being used to determine value, only approximate volume. There are no financial transactions that take place based on this information. This system is not suitable for further development for log measurement as the basis of payment for log sales as it uses estimates and assumptions on void size and frequency that vary in accuracy. This system is simple and efficient to use, however its application is generally limited to its current purpose.

### *8.3 Vision Systems*

The National Research Council (NRC) of Canada has investigated systems using vision technology, however the extremely high cost of this technology has constrained development.

Vision systems are highly technical, and are developed around expensive and highly sensitive equipment. Trials have been performed in Montreal on mounting these types of systems onto harvesting machinery to assess logs as they are produced. General comments from researchers who have trialled this type of technology remind us that a mechanical lens is constrained compared to what the human eye is able to discern. Therefore in poor light conditions these systems always have difficulty differentiating between shade and dark objects. In the test environments where these types of systems are exposed to dust, vibration and mechanical forces these systems are currently not reliable.

New developments for vision systems include mounting lenses in permanent structures, and assessing truck loads as they pass by at slow speeds. Obviously this type of system is only able to assess ‘cross-loaded’ trailers of short length. However there may still be applications for this type of system, particularly for preservation and short pulp products. Further investigation into assessing trailer loads has proven that it is difficult and not practical to have all of the logs stacked so that the ends are all neatly visible. Once some of the log ends are in shadows the accuracy diminishes.

However, NRC estimates that sensing technology doubles every 18 months, so perhaps in future this type of system can be further developed. Currently electronics are a major cost component, along with mechanical processes within the components, but technology will potentially reduce these hurdles. This is currently a specialist industry, but the industrial market is growing, this will help to reduce the future costs. Currently these systems are tailor made for specific industries and therefore are not in mass production, and hence very expensive. The developers suggest that sensor quality has improved dramatically in recent years, previously quality of parts was a limiting factor, now it is generally only the cost!

NRC investigated using three cameras on different angles, directed at the same point for accuracy, to assess the ends of conventionally long-loaded trailers. They are now planning using a single camera with mirrors to reduce the cost. They have considered developing a camera that would drop down in between bays of a conventionally long-loaded trailer, however with more moving parts, reliability is compromised, maintenance increases and the product is less stable. NRC estimate that the development cost for such systems is more than CA$ 750,000 (A$700,000).

### 8.4 Portable Laser Scanner

FERIC developed a research proposal for a trailer mounted sawmill type log scanner to be transported around the field and used for sample scaling. The forest owners, who did not see this technology as cost effective and important for Canadian conditions, did not support this proposal.

### 8.5 Forwarder Weight Scales

Forwarder manufacturers are currently developing the incorporation of weight scales on machines. These facilities are already available as after-market additions by third party manufacturers. Once this technology is accepted and integrated into common harvesting systems, it will offer opportunities for the harvesting operator to monitor segments of the harvesting operations.

This equipment may provide a source of 'validation' information that could be used in conjunction with other measuring systems. It is expected that weight scales on forwarders will be used in the same manner as on-board scales are used on log trucks today. The primary benefits will be mass management and load optimisation. It is not likely that information produced from this type of system could be used as the basis of financial transactions between the buyer and seller. Perhaps the harvesting contractors will be able to use this information for piecework payment of employees.

### 8.6 Colour Coding Harvester Heads

Most of the major harvesting machinery manufacturers currently offer the ability for cut-to-length harvesting heads to mark the ends of logs during processing with a spray of colour paint (Figure 12).

These systems are fitted as a standard accessory to a high proportion of harvesting machines operating in Scandinavia. The colour coding mechanisms are able to spray up to three colours in combination. If you include applying no colour as an identifier, this gives eight possible combinations for identification of different products. Colour coding attachments to harvesting heads can be retrospectively fitted to most harvesting machinery.

For all of the systems available on the market today, the colour is applied through individual nozzles, one for each colour, and the order of colour application cannot be changed. Partek are investigating controlling the order of colour application to produce a bar-code effect of colour. This would allow a larger number of different codes to be applied, and increase the applications where this system could be used.

Figure 12. Colour coding harvesting head attachment, Sweden


Figure 13. Colour coding harvesting head paint reservoir – two colour, Sweden.

# 9 Conclusion

All of the log measurement systems observed varied in their use of technology, processes and accuracy, but were successful in their appropriate environment. These systems shared four common components, they all:

1. Were implemented regionally (or indeed across an entire country or province);
2. Used a single measurement method which was accepted and agreed to by all parties in the supply chain;
3. Utilised a secondary system to validate and confirm delivery;
4. Included appropriate regulation with agreed penalties.

More important than these four commonalities is the associated culture that each system operates within. Although these systems were successful in each of the locations visited, it is not necessary or likely that any of them would work if they were transferred to another region and culture.

Log measurement systems that identify individual logs provide the highest level of functionality and information tracking along the supply chain. However this type of system also generally has the highest cost. This high level of information is not necessarily required by all supply systems, and a suitable compromise for cost and detailed information is identifying measurement information by loads, not logs. This type of system must be operated in conjunction with rigorous segregation of all loads, a process that is performed with ease in Sweden and Finland. In Sweden measurement by the Timber Measurement Association at the mill demands accurate identification of the supplier, which must be managed by clear separation of deliveries. Every delivery is marked to identify the supplier.

Whether it is more efficient to collect individual log information for higher value products, or to collect information per delivery load, depends upon the value which the custodian of the product places of this information.

Identifying individual logs with supplier marking was common observed. This process is relatively simple and ‘low-tech’ and is often performed using hammer stamps.

Any system that involves the identification of individual logs or loads must have clear and well defined procedures for exceptional circumstances, such as when logs or loads lose their identification. As with all systems it will be these exceptional circumstances that require the greatest control. Starker Forests sort yard system in Oregon manages log tracking and reconciliation of logs where the bar-codes are ‘missing’ extremely well. This system would be transferable to mill yard deliveries from the forest. However the cost of measurement is extremely high (US$ 4.00 per m3), like all systems you get what you pay for! These types of systems where log measurement information travels with the log, commonly as bar codes are very costly and were only used in places where high value logs are being individually handled for another process, usually grading or product sorting. This is the case for TimberWest in British Columbia who supply internal customers and export to higher value export markets. They have the largest private timberlands in British Columbia and harvests approx 3.6 million m3 annually of predominantly Douglas fir and hemlock. Douglas fir receives a premium of 75% over hemlock for equivalent grade logs.

The cost effectiveness of any measurement system is dependant upon the value of the logs, and generally the size of the logs. Small log systems such as Quebec, Newfoundland, Sweden and Finland focus on developing mechanized techniques for log measurement to replace partial or sample manual measurement, which are not cost efficient.

In Sweden it is the view of the major harvesting machinery manufacturers and many harvesting contractors that eventually most volume will be measured and purchased based on volume information produced by the harvesting machines. This may be possible in countries where this information is already commonly accepted, however this view is generally not shared by the processing industry, or the forest owners in these regions, who have confidence in the current system of scaling. It is likely that the harvesting contractors will continue to use this information to monitor and validate payments made by the Timber Measurement Association. The ambition of the harvester manufacturers to be the major provider of harvesting information in Finland and Sweden is predictable, as is the confidence that the harvesting contractors have in their equipment, and the ownership that they have over the information collected.

Measurement information produced by harvesting machines may be suitable to validate another measurement system without the need to track specific logs in Australia. This information is not suitable as the primary source of measurement information in Australia because the industry already expects more accurate information than currently produced by these machines. Additional to this physical requirement is the large cultural shift associated with changing the custodian of the measurement information used as the basis for financial transactions.

The use of harvesting machine volume measurement for the purpose of pre sale estimation, as used in Finland and Sweden is suitable for Australia. However in Australia some wood from coupes is generally delivered prior to completion of harvesting, and most forest owners have a culture of pre harvest inventory. In an environment where contractors had a high proportion of ‘modern’ harvesting machines, it would be possible to replace manual inventory with harvesting machine volume estimates. But again this would mean an enormous cultural shift where the harvesting operation was responsible for information that is currently controlled by the forest owner.

In forestry environments where harvesting is performed by contract operators, the contract conditions have an influence on the development of technologies. A short contract length means continual price revision and competition, but longer contracts encourage contractors to undertake development and benefit from any improvements. A harvesting contractor visited in Sweden who contracted to a single sawmill on a one year contract described an Australian five year contract, extended an additional five years as a 'gold' contract, relating it to finding gold!

FERIC in Canada have performed regular reviews of contract terms and conditions. Here they find that contractors need a payback for using new technology and taking risks. They also require longer-term contracts to assure ongoing viability. The current system in Canada does not guarantee either of these. Restructuring of contracts would in the long term encourage innovation and reduce wood costs. Currently successful innovation by enterprising contractors to reduce operating costs may mean reduced pay rates to the contractor. As well innovation that provides secondary benefits, such as improved environmental performance may not benefit the contractor at all. In these cases there is little incentive for the contractor to take the risk of implementing new technology. TimberWest in British Columbia harvests approximately half of its volume using its own logging crews, and uses independent contractors for the remaining half. This gives them a strong position when it comes to negotiating contract prices.

The culture of Australian contractors is very different to the Scandinavian culture, as the laws and regulations in Scandinavia have influenced their evolution. In Australia the industry has not had the same environment. It is still common in Australia for harvesting and transport operators to not complete log books and haulage notes, or incorrectly completed books. This does not occur in Sweden or Finland where the penalties for non-compliance with the regulations are strict and commonly enforced.

Manual log measurement is tedious and its importance is generally not well recognized in Australia, unlike many of the areas visited for this fellowship. Manual scaling was only observed in processes where manual log grading was the primary function, such as Canada and the United States. In Finland and Sweden the grading function is performed as logs pass through an optical scanner, which eliminates the need for manual scaling.

All of the new technologies observed have varying degrees of practical suitability. However when compared against manual measurement they offer the potential to produce consistent and repeatable without having to match labour requirements to wood flow.

For all of the different systems observed, optical scanners were the most accurate and reliable because they are static, perform a single function, are easy to maintain and not limited by function or size. In comparison, harvesting machine measurements do not have these benefits, and currently are not as accurate or reliable, especially in regions other than Scandinavia.

For countries where an external body audits and verifies the log measurement information, such as the MoF in Canada or the Timber Measurement Association in Sweden, the purchaser is not required to remeasure logs after purchase. All they are required to do is validate the number of logs or bundles against that specified by the sales contract. This system is transferable to Australia, irrespective of the measurement system used.

In order to create trust in the measurements produced by any custodian in the supply chain, greater use could be made of independent quality certification. This applies to everyone in the supply chain, including harvesting contractors. This may not be appropriate for all current contractors, but in today's contracting environment the cost of equipment dictates that contracting organizations are run as large businesses even if they are a family enterprise. The major harvesting equipment manufacturers provide the capability to calibrate measurement equipment on their machines, a function that is monitored and reported by the on-board computer. This process would be simple to comply with independent quality certification.

TimberWest in British Columbia is certified to the International Standards Organization (ISO) for all operations, including forestry. They have the largest private timberlands in British Columbia and harvests approx 3.6 million m3 annually. This covers all of their log sorting and scaling operations, and allows them to promote measurement quantities that their customers have confidence in.

Calibration of optical scanners at purchaser sawmills could also be addressed by independent quality certification. Contract documents could include the calibration requirement, or that independent quality certification be satisfied. The addition cost of certification to the purchaser could be paid for by the savings in costs from the measurement system that it replaces.

# 10 Recommendations

Reviews of log measurement systems have been occurring consistently by both large-scale suppliers and purchasers. Historically alternatives that considered the use of optical scanners at the processing centres concluded that the costs associated with the installation of such technologies made them non-viable.

However the current situation is that most sawmills of reasonable scale operating in today's competitive environment have this equipment already installed for the purpose of optimising cutting patterns. A system that utilises this existing infrastructure would not need to justify the purchase of such equipment in most situations.

Using measurement information produced by optical scanners at sawmills is the most accurate method to determine quantity. This system could replace manual measurement systems and provide more accurate and repeatable information. This avoids issues associated with labour requirements matching log flow and productivity. If this system was used in conjunction with identifying and segregating loads individually, then both the forest owner and the purchaser will have access to accurate information which can be traced back to the coupe.

In the process to determine quantity, if allowances are required for bark thickness, conversion from weight to volume, density, and shape then the optimal system should not be influenced by any of these factors. A system that scanned logs irrespective of weight, after debarking by viewing the entire log would satisfy these conditions. Such systems already exist at many processing facilities within the Australian industry.

As discussed previously, one of the four common components of successful systems is the use of a single measurement method that is accepted and agreed to by all parties in the supply chain. Given that most reasonable scale sawmills already use optical scanners, a log measurement system that does not include these facilities will always be subject to comparison and conversion between measurements. If it is agreed that a single measurement system is the best way to agreed measurement information, then it should make use of these accurate facilities.

Independent certification of optical scanner systems can be used to satisfy audit requirements. This is a similar philosophy to the current verification of public weighbridge facilities used in the Australian industry today where a government contracted calibration authority certifies these facilities. Most importantly for any system is the mutual development of penalties for non-conformance, these must be of sufficient magnitude to deter non-conformance, and must be strictly adhered to.

Such a system requires a cultural shift in regions of Australia where the forest owner is currently responsible for log measurement. This should be achievable as it involves swapping the responsibility in existing agreements between the supplier and the purchaser who have already developed trust by their historical arrangements.

It is essential in this type of system to employ a secondary validation system to confirm delivery quantity and most audit systems will require this. Given the cultural and industry acceptance of weighbridges in Australia, this is an obvious asset that could be utilised for validation. So too could other technologies mentioned previously be used for this purpose, including harvesting machine measurements, given appropriate constraints. The most basic measure of validation for other than the smallest of log sizes is a log count. This can easily be managed by the truck driver, and can be performed while the truck stops at a weighbridge. Unmanned weighbridges are proven suitable to obtain load weights, and small delivery locations without access to such facilities could possibly use on-board scales – with appropriate calibration control, as discussed previously. This acknowledges the existing culture and satisfies legal requirements in the use weigh bridges, with the existence of infrastructure to support this.

In regions where a number of small-scale sawmills exist that do not have the same infrastructure of larger sawmills, a small roving crew of manual measurers could supplement any of these systems. This crew would then only be required to measure a minor proportion of the total, with the majority of logs measured by a mechanical system.

Improved log measurement will improve product segregation and assist in targeting specific markets. It will also provide more detailed information by product and therefore help command higher prices for the forest owner. Currently for all custodian transactions, if the buyer thinks that the agreed measurement technique will overestimate the quantity, then he will reduce the price offered accordingly. This introduces another estimate in determining quantity.

For measurement systems that identify individual logs, primarily bar-coding systems, the four common components of the successful operations mentioned previously suggest that it is important for this (and all types of) system to be implement regionally, and not locally. If different owners develop different non-compatible bar coding systems the log-specific information tracking is limited to the log yard of each owner. Similar to the grocery-retail industry, the agreement of a single bar code system format for all participants within a region will allow transfer of information irrespective of custodian and avoid multiple database interaction. With a universal format the bar code and hence the actual log is used as the carrier of the item specific information and not a database. This makes the process of obtaining log specific information simple and efficient the along the entire supply chain.

Sales systems based on conversion from weight to volume can be replaced by alternative measurement systems. This avoids issues of seasonal variation in density factors, and the confusion when both the buyer and the seller wish to use factors that are advantageous to each other. In these conversion measurement systems the purchaser and the seller have their own estimation of the conversion accuracy, and this is considered when negotiating price. The sales process would be simpler if these assumptions were clearly stated and consistent for both parties. Markets that are based on agreed and fair measures by both parties are more sustainable than when one or both parties question the confidence or validity of the underlying transaction information. This type of system is often justified for small logs. However small diameter logs are more influenced by variation in density from bark thickness, age, season, site, log position within the tree, and time since felling.

Pulpwood sales are generally based on weight without conversion. It is common for some Australian sales to be based on a straight conversion where one cubic metre is assumed to be equivalent to one tonne. Although this is a biased assumption both parties make allowance in their price negotiation to reflect their true estimate of conversion. The assumption that pulpwood can be sold by volume assuming a straight conversion from weight originated when pulpwood was a truly low value product in surplus and only contributed to a minor component of the forest owner's revenue. This is not the situation in the 21st century, however it is still not as cost effective to measure volume as it is to measure weight.

A simple alternative is for sales based on weight that can rely on weighbridges that can be unmanned. Where current pulpwood is sold on volume, this would require cultural change, however the pulp industry is centred around weight transactions, so the change required is not large. The forest owner would still require knowledge of conversion factors for consistency between sawlog and pulpwood production. This information already exists and as discussed is currently in common use.

The concept of sawlog sales based on weight would only require the simple use of weighbridges to identify the quantity for transactions. This would shift the conversion from weight to volume to become the responsibility of the sawmill purchaser. This would not reduce the need for conversion, only transfer the responsibility, but perhaps the sawmills are the custodian most effected by this conversion, and therefore should be responsible. The associated cultural change across Australia for this concept is probably not achievable. Of course simply shifting to sales at the stump solves the measurement problems for the forest owner, but simply transfers them to the purchaser.

Harvesting managers are always going to be interested in weight information because this is the basis of all their costs. A large forest owner will always be expected to understand the relationship between weight and volume to negotiate harvest and transport rates.

Most systems used for log measurement can benefit from recording supplier information on individual sawlogs. Use of a stamp hammer in the forest is a simple method that is easy to introduce. Different codes can identify the harvesting operation and coupe, and colour spray codes available from modern harvesting equipment in CTL operations could be introduced to identify products. If logs are identified by load or bundle, then the information from a haulage note attached to one log per bundle can be obtained at the measuring location. This can include validation information such as a log count, or perhaps the bundle or load weight. If the driver performs counting and weighing functions, then delivery can occur twenty-four hours per day, and are only constrained by unloading facilities.

Modifying the feed rollers on CTL machines to include a stamp similar to a hammer stamp could further develop this process. The harvesting process could leave the imprint of the feed roller code along each stem, marking each log. Depending on the requirement for this type of information, it would be possible to change these feed roller codes for each coupe, or even more frequently. For manual harvesting operations it would also be possible to create 'grapple codes' with stamp marks on the inside of grapple arms, and stamping occurred during log handling. It would be possible to design interchangeable coded studs that were inserted and swapped onto either of these marking systems. A well managed system could record changes to codes and produce corresponding date information for each log.

For low value operations where individual identification of logs (and even loads) is not economically viable, the use of feed roller codes could by useful to identify supplier information on each log. In plantation forestry most early thinning operations that produce pulpwood are machine harvested so this could be implemented as an inexpensive and simple modification to implement.

To satisfy road transport regulations in Australia trucks are required to carry delivery load information for each load. These are independently calibrated and accepted in Australia as correct. It is also common for trucks to incorporate onboard scales to maximise payloads. This weight information can be used as a secondary measurement validation (along with log counts). Calibration could be performed at delivery locations that could have a simple calibration weight of known weight (eg. 10 tonne) temporarily loaded and unloaded to calibrate the truck scales.

## Appendix 1 References


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## Appendix 2 Organisations Visited

British Columbia, Canada

- Forest Engineering Research Institute of Canada – Western Division
- University of British Columbia
- TimberWest Head Office
- TimberWest Crofton
- Weyerhaeuser Nanaimo

Quebec, Canada

- Forest Engineering Research Institute of Canada – Eastern Division

Ottawa, Canada

- National Research Council Canada

Washington State, United States of America

- Longview Fibre Company
- Weyerhaeuser Longview

Oregon, United States of America

- Oregon State University
- Oregon State University Corvallis Research Forests
- Starker Forest Inc
- Anonymous Harvesting Contractors

Finland

- Timberjack Oy
- Lako Oy
- Anonymous Harvesting Contractors

Sweden

- Partek Forest AB
- Swedish University of Agricultural Sciences, Uppsala
- Swedish Timber Measurement Council
- Mellanskog Industri AB
- Heby Sawmill, Heby
- Forestry Research Institute of Sweden (SkogForsk)
- Anonymous Harvesting Contractors
- Skogstjänst (Droppen)
- Techno-Matic Ltd
- CC Systems AB