Resin defect impacts on the value of graded recovery and evaluation of technologies for internal defect detection in slash pine logs
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Prepared for the Forest and Wood Products Research and Development Corporation

by

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1. **PROJECT BACKGROUND**

The occurrence and severity of resin defects in slash pine varies considerably with environment and within stems. The economic consequences of resin defects are significant as they are a major cause of lost recovery and sawn product rejection for solid wood processors in Queensland and can result in shifts in market preference to alternative products; both other wood resources and non-wood products. Resin shake is the major cause of lost recovery and sawn product rejection for solid wood processors in Queensland but the presence of resin streaks also impacts on sawn, veneer and reconstituted products. Resin shake normally affects about 2% of green off saw (GOS) recovery from good sites but sawn board rejection rates are typically 4 to 5% for clearfall sawmillers and this level can be much higher from severely affected sites.

The cost to Queensland forest industry processors of rejecting resin defect affected wood and using it as fuel, or chipping it to sell as a low value input to reconstituted wood products, is estimated to be at least $4 to $5 million/annum. The only current opportunity for the sawyer to assess presence and severity of resin defect at primary log breakdown is what appears on the ends of the log as it is presented and oriented for chipper-cant or other breakdown sawing. However, the correlation between visible defects on log ends and the proportion of recovered wood affected by it, as well as the severity of the defects present, has been found to be weak in previous sawing studies recovering visually graded non-structural board products.

In Queensland, the economic consequences of resin defects are highly significant. Resin shake is the major cause of lost recovery and sawn product rejection for solid wood processors in Queensland but the presence of resin streaks also impacts on sawn, veneer and reconstituted products. Resin shake normally affects about 2% of GOS recovery from good sites but sawn board rejection rates are typically 4 to 5% for Weyco and Hyne and Son and this level can exceed 40% from severely affected sites.

This project was designed to address this current and important timber industry problem by assessing tools needed to segregate badly affected logs. We attempted to model resin defect impacts on machine graded structural sawn wood recovery using external indicators, and we tested the efficacy of a range of internal log scanning systems. Both lines of research aimed to identify logs that will not produce enough value added product recovery to justify sawing and processing costs. Segregating these logs would create opportunities for them to be diverted to alternative uses so as to improve sawmill economic recoveries, efficiencies and profitability and the total value of all recovered products from a resin defect prone site.

The project objectives were to:

- Undertake a sawing study to capture recovery and product grade recovery data from logs displaying a range of resin defects on log ends, in a form suitable for predictive modelling of the impact of resin defects (streak and shake) on machine graded pine (MGP) recovery and product value.
- Use the outputs from the sawing study to attempt to produce a model that predicts the impact of resin defects in slash pine logs primarily on dried-dressed recovery and MGP structural product value from classes of resin defect assessable on log ends. Such a model is needed to identify critical levels of defect that make it uneconomic to recover the value adding costs of sawing, seasoning, dressing and grading.
• Compare a range of currently available internal scanning technologies to assess their capability to rapidly delineate the extent and severity of resin streak and shake defects (and knots or wood density variation as a secondary objective) in green, debarked logs. Scan results were compared to digital images or reconstructions of the resin and knot patterns within the sections, with particular emphasis on resin shakes as the most serious defect.

• Assess the practicalities of using and implementing these technologies in an industrial environment considering scan speeds and costs for adoption or development by processors.

1.1 Technical basis of the project

The sawing study and modelling techniques used in this project reflect the combined experience of researchers from Horticulture and Forestry Science, DPI&F and Weyerhaeuser Australia. The project applied a range of existing knowledge and experience to a ‘new’ problem in that the level of descriptive data capture and modelling undertaken for resin defects has not previously been done for this purpose. Similar techniques have been used by CSIRO DFFP and State Forests of NSW in sawing studies and the approach can be considered state-of-the-art for log and board identification and tracking.

The internal log scanning technologies are all technologies that are at prototype stage or have been used for internal log scanning research. Some x-ray scanning is starting to be operationalised in Europe. However, this application to resin defects is quite novel and is a new test of the capabilities of the technologies. Most scanning has been undertaken to determine knot location and architecture within logs to optimize high value sawing recovery of clear wood or to favour surface grain patterns (eg backsawn figure). Some work has been done to detect splits in large cant sections. The state-of-the-art technologies discussed and tested with the groups at Mississippi State (radio frequency) and Virginia Tech (ultrasonics – considered but not tested) use prototype research tools specifically applied to other wood research applications in both round wood poles and sawn boards. Dr John Davis was specifically included in this proposal due to his pre-eminent status as the foremost authority on log scanning within Australia and his international recognition in this field. He was able to access and use medical facilities for x-ray helical computed tomography (CT) and x-ray digital radiography (DR) scans, which provided a quite adequate test of these technologies without the expense of sending material to Europe where dedicated wood research facilities are available.

1.1.1 CT and DR scanning:

Dr. Davis established industrial x-ray imaging research at Monash University in 1985 and has extensive local and international experience in its application to the timber industry. He was a 1986 Gottstein Fellow (internal log scanning), Principal Investigator of the DIST-industry funded Glass Log Project (1994-6) and has collaborated with most of the key international research and scanning equipment industry leaders in the field of x-ray scanning of logs and forest products. He has published widely in the field of x-ray tomography and x-ray optics.

1.1.2 Radio frequency scanning:

Dr Philip Steele presented a paper titled “Electrical Capacitance Method for Detection of Decay in Treated Poles” to the ScanTech 2003 Conference (10th International Conference on Scanning Technology and Process Optimisation for the Wood Industry), co-authored with Jerome Cooper. This was a follow up to their paper to ScanTech 2001 “Determining Lumber Strength with Radio Frequency Scanning”. Quoting from the 2003 paper: “The potential for detecting rot in power poles using an electrical capacitance method”. Pole sections were scanned over their length by a laboratory prototype that applied 250, 500 and
2000 kHz radio frequency signals to opposed 1-inch diameter metal electrodes in contact with the pole surface. Signal voltage attenuation and phase shift values for sound and decayed wood sections were recorded. Radio frequency signals of 2000 kHz yielded the greatest difference in attenuation and phase shift response between sound and decayed wood. Although differentiation of sound and decayed wood with signal attenuation appeared impractical, signal phase shift performed consistently. Differentiation between sound and decayed wood by analysis of phase shift response for signal frequencies of 2000 kHz and above and appears to have considerable potential for this purpose. The scanning work undertaken for this project involved a similar approach.

### 1.1.3 Low intensity microwave

Keam Holdem has an existing involvement in the timber industry. They have worked on a medium speed timber microwave profiling system in association with Weyerhaeuser. Microwave sensing is well suited to detecting timber properties such as changes in moisture content and density as well as some macro-chemical properties at a medium level of measurement resolution. The presence of resin and cracks typically affects one or more of these timber properties, so it was thought that this technology might detect resin defects by comparing affected wood with uniform lumber. Previous work with low intensity microwave suggested that timber defects of >2cm were detectable in sawn timber planks.

### 1.1.4 References


2. INTERNAL LOG SCANNING TECHNOLOGY COMPARISON STUDY

2.1 Summary
Internal scanning investigations of slash pine short-length log samples were undertaken by measurement providers in Australia, New Zealand and the USA. The aim of these investigations was to ascertain the capability of currently available internal scanning techniques to rapidly delineate the extent and severity of resin streak and resin shake defects in green debarked logs. The scanning techniques tested were x-ray digital radiography, x-ray helical computed tomography, low intensity microwave reflection and radio frequency scanning.

This report summarises the key outcomes of each scanning investigation and has assessed, at this stage, that only two of the scanning techniques are potentially viable, namely, x-ray helical computed tomography and low power microwave reflection. However, because the microwave investigation was essentially a feasibility study, further investigation is required to clearly determine the practicality of the technique within a real log scanning environment.

X-ray CT is a mature technology with capabilities that are probably now able to match the performance demands of the timber industry. It certainly remains the only proven internal log scanning technology. However, issues related to capital cost, costs associated with systems integration, in-service availability and, most importantly, the formation of a joint venture between an equipment manufacturer and a motivated timber company or a consortium of interest are problematic.

Internal log scanning is unlikely to attract manufacturing interest to produce commercial prototypes unless a whole of forest industry business case is developed and supported.

2.2 Introduction
Internal scanning investigations of slash pine short-length log samples were undertaken by measurement providers in Australia, New Zealand and the USA. The aim of these investigations was to ascertain the capability of currently available internal scanning techniques to rapidly delineate the extent and severity of resin streak and shake defects in green debarked logs. A secondary objective was to also ascertain their capability to detect knot position and size.

It was initially intended that the scanning techniques include x-ray digital radiography, x-ray helical computed tomography, low intensity microwave reflection, radio frequency scanning and ultrasound scanning. However, while ultrasound techniques (USDA Forest Service) have had laboratory and field success in the scanning of sawn boards, the method was ultimately deemed unsuitable for the scanning of logs as continuous transducer contact with the wood surface is needed for reliable resolution; this is readily achieved in dimensioned lumber but requires considerable plant development work to achieve in unprocessed logs. Additionally, it was impractical for the USDA team at Blacksburg Virginia to undertake tests within the time-frame required for this project. A summary of the measurement providers and their scanning techniques compared in this project is given below.
The key outcome of the scanning investigation is that the technology assessments suggest that only two of the scanning techniques are potentially viable, namely, X-ray helical computed tomography and low power microwave reflection. However, because the microwave investigation was essentially a feasibility study, if this technology is to be fully tested further investigation is needed to clearly determine the practicality of the technique within a commercial log scanning environment.

2.3 Test samples

Sets of green log samples were collected as short log sections about 850mm long. The samples were docked from logs in the Weyerhaeuser Australia log yard at Caboolture and were sourced from south east Queensland; either from Toolara State Forest, Caloundra Downs or Beerburrum State Forest. Comparable sets of material of very similar size and resin defect occurrence/severity were selected. This required surveying log stacks and identifying likely sample logs displaying resin defect on cut ends of mild, medium and severe extent. Each set of logs assembled for testing by each measurement provider contained a sample of each resin class and contained at least one prominent knot whorl (3 to 4 knots). An additional severe class sample was sent to Dr. Davis to allow this sample to be validated by longitudinal sawing of the log. This allowed a comparison of this method of validation of scanning results versus the cross-sectional dissection used for all other samples as described in the detailed reports.

All bark was removed from the log samples and they were clearly identified with uniquely numbered log tags. The log samples were plastic wrapped to prevent drying during transport. They were shipped by air freight so that the time between collection and testing was minimised so that the samples closely represented the green condition of typical log-yard material, pre-processing. The samples for Dr. Davis were transported to Cairns using express road freight.

To meet quarantine phytosanitary requirements the samples for Keam Holdem and Mississippi State University were heat treated in a research kiln, with high relative humidity control to minimise moisture loss, for a minimum of 75 minutes continuously once a minimum core temperature of > 70°C was achieved. Prior to shipment they were inspected by the Australian Quarantine Inspection Service and a Phytosanitary Certificate issued.

Description of the log samples supplied to Dr. Davis are provided below and are typical of the samples supplied to all measurement providers. All log samples (Table 2 and Figure 1) were debarked, wrapped in plastic wrap and shipped from DPI&F to Cairns for x-ray measurement. Significant moisture loss was observed in all samples except 474, reflecting the length of time the logs had spent in the Caboolture log yard.

<table>
<thead>
<tr>
<th>Measurement Provider</th>
<th>Scanning Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr John R. Davis</td>
<td>X-ray Digital Radiography</td>
</tr>
<tr>
<td>Cairns, Queensland</td>
<td>X-ray Helical Computed Tomography</td>
</tr>
<tr>
<td>Keam Holdem Associates</td>
<td>Low Power Microwave Reflection</td>
</tr>
<tr>
<td>Auckland, NZ</td>
<td></td>
</tr>
<tr>
<td>Mississippi State University</td>
<td>Electrical Impedance Tomography</td>
</tr>
<tr>
<td>Department of Forest Products</td>
<td>(Through-Log-Density-Detector)</td>
</tr>
</tbody>
</table>
Table 2. Log sample description

<table>
<thead>
<tr>
<th>Log Sample</th>
<th>Length (mm)</th>
<th>Diameter (mm)</th>
<th>External Condition</th>
<th>Resin Defect Assessment From Log Ends</th>
</tr>
</thead>
<tbody>
<tr>
<td>474</td>
<td>925</td>
<td>270</td>
<td>Debarked Groove at LED Wrapped in plastic foil</td>
<td>Severe</td>
</tr>
<tr>
<td>475</td>
<td>1000</td>
<td>240</td>
<td>Debarked Groove at LED Wrapped in plastic foil</td>
<td>Severe</td>
</tr>
<tr>
<td>476</td>
<td>950</td>
<td>210</td>
<td>Debarked Groove at LED Wrapped in plastic foil</td>
<td>Moderate</td>
</tr>
<tr>
<td>477</td>
<td>900</td>
<td>210</td>
<td>Debarked Wrapped in plastic foil Groove at SED</td>
<td>Bad</td>
</tr>
</tbody>
</table>

Figure 1. Four slash pine log samples 474 – 477
2.4 Outcomes of the scanning investigations
An assessment of the four scanning techniques is provided below.

2.4.1 X-ray digital radiography
X-ray digital radiography was rejected because it was not possible to obtain contrast between the resin defect structure and the surrounding sapwood dominated matrix (see Figure 2 below). The large sapwood band in slash pine occupies approximately 90% or more of the log volume and this characteristic feature also makes it difficult to reveal knot whorls along the stem.

![Figure 2. X-ray digital radiographs of slash pine samples 474, 475, 476 and 477. The gray scale window centre and width for each image were adjusted for best contrast. While knot whorls and heartwood are apparent in each image, the resin defect is not revealed.]

2.4.2 X-ray helical computed tomography
Computed tomography is able to accurately measure the resin defect structure and the knot whorl distribution within slash pine logs (see Figure 3). The scanning measurements clearly showed, within the resolution constraints of the scanner that the presence of resin is always associated with the existence of wood tissue fracture or shake. Some of these fractures are not clearly visible to the naked eye without high magnification or other artificial enhancement. The general morphology of resin defect structure appears to follow the spiral grain habit of the stem (see Figure 4).

CT scanning basically sets the benchmark and datum for other non-destructive scanning techniques. The current status of the CT technology suggests that the internal information
obtained in this study can be achieved under real industrial conditions. Given the very detailed level of information obtained it would seem that considerable flexibility is available to tailor the sensitivity of the technology to meet industrial productivity requirements.

**Figure 3.** Sample 475 digital photographs and CT images of corresponding axial cross-sections
Figure 4. Three-dimensional reconstructions of the resin defect and knot whorl structures in samples 474 (bottom) and 475 (top) with the butt or LED end at the right. The resin defect is made visible because of the high density of the resin-loaded latewood bands. The bottom image clearly shows the spiral nature of the resin-fracture system as it apparently follows the right-handed spiral grain habit of the log sample.
2.4.3 Low power microwave reflection

While the results of this study demonstrate the feasibility to detect and estimate the size of shake or cracks within the log samples, there is good evidence to suggest that the frequency domain analysis technique can yield reasonably accurate and reliable information about the radial and longitudinal extent of the resin defect structure within a log. This study focussed upon shake/crack and knot detection rather than the detection of resin flooding as a separate feature.

The measurement provider is confident that the precision and validity of the reported results (example in Figure 5) could be considerably improved and extended to enable a coarse resolution mapping of the longitudinal location of knots and, importantly, the radial and longitudinal distribution of the resin defect structure. However, further investigations will be required to determine whether the technique can provide the necessary internal information when practical parameters such as variable air gaps between source and log, realistic linear log speeds and larger diameter logs are considered. Therefore, considerable further testing work is required to fully evaluate whether this technology can meet the requirements of industrial conditions.

![Log 1 Calibration model](image)

**Figure 5.** Log 1 Calibration model - correlation coefficient of 0.76 between the low power microwave reading and the size of the defects, and a standard error of 18 mm

2.4.4 Electrical impedance tomography

This is a technique that attempts to produce coarse spatial resolution maps of the distribution of electrical conductivity within a cross-sectional slice of a log. The technique has attracted attention in medical imaging and in the monitoring of complex dynamic fluid flows in industrial pipeline systems. The measurement providers have expertise in the application of radiofrequency techniques to the scanning of sawn boards and in recent years have extended their scanning interests to the EIT technique known as the Through-Log-Density-Detector (TLDD).

For the purposes of this test the laboratory measurement procedure required that the log be initially shaved to approximate a regular cylinder and a set of eight equidistantly-spaced electrodes were arranged in a circle around the log sample prior to measurements being taken. The technique as it applies to logs has been patented by the measurement provider.
Our assessment of the EIT results is that this technique be rejected for further development since it appears to be essentially a laboratory procedure and has not produced reliable results at significant depths into the log cross-sections. The large sapwood band in slash pine only appears to have been penetrated by this technique to the depth of the outer 6 – 7 growth rings. Further, it would seem that the measurement methodology is seriously flawed since the reliable and valid application of metallic electrodes to the surface of a log is not achievable even in the laboratory test. It is also well known within the EIT field that large changes in the internal electrical conductivity distribution can result in small and difficult to measure voltage changes. Finally, the very nature of the EIT technique does not appear to be compatible with industrial log scanning.

2.5 Conclusion: proven and potentially viable internal scanning methods

Of the scanning techniques assessed in this investigation, only x-ray CT and microwave reflection remain as proven and potentially viable log scanning methods, respectively.

X-ray CT is a mature technology with capabilities that are probably now able to match the performance demands of the timber industry. It certainly remains the only proven internal log scanning technology. However, issues related to capital cost, costs associated with systems integration, in-service availability and, most importantly, the formation of a joint venture between an equipment manufacturer and a motivated timber company or a consortium of interest are problematic.

Although the microwave results represent a feasibility study, there is sufficient evidence to suggest that a further exhaustive proof-of-concept program may be justified to determine whether the technique could satisfy the following requirements:

- Precisely define the resin structure defect (cracks + resin) consistent with the known distribution as revealed by x-ray CT
- Demonstrate that internal knots can be differentiated from zones of resin streaking/flooding
- Show that the internal distribution of resin defect (and possibly knots) can be longitudinally mapped and be consistent with the results obtained from x-ray CT.
- Demonstrate that certain practicality factors can be satisfied so that internal information can be acceptably determined. The factors will include:
  - Measurement of internal features using variable air gaps between the microwave source and the log surface.
  - Measurement of internal features assuming linear log speeds (past the microwave source) of up to 100 m/min.

The capital costs associated with the introduction of an acceptable commercial microwave log scanning technology are likely to be considerably less than the costs associated with x-ray CT. However, this assumption has yet to be tested. Financial modelling involving the adoption of either of these two technologies has also to be explored.

2.6 Future work

The project management team met at Gympie in May 2005 and discussed what the management team, in particular the industry partners, thought of the trial results and their interest in further investigating the implementation of internal log scanning.

Microwave reflection technology was considered simpler to adopt than x-ray due to the up-front hardware costs and the extra shielding and workplace health and safety infrastructure needed to develop an x-ray based system. The latter complexities also may be more limiting to the adoption of x-ray technology in a road-side harvesting situation versus mill
log yard. However, the economic benefits of harvest versus log yard screening/diversion would need to be evaluated.

As indicated above, the trial results for the microwave reflection technology are positive in terms of the initial feasibility of this technique but they need confirmation in a follow-up test that addresses some of the practical issues identified as potentially limiting for commercial adoption. Using helical CT scanning as the proven reference technique, a follow-up test would involve CT scanning several more logs to identify 1 or 2 that contain the full suite of features that microwave reflection would need to detect with some degree of certainty to substantiate its value for development to a prototype stage. The key features to be tested would include:

- sensitivity to detection of a resin filled crack versus an open crack with an air-filled void - i.e. can microwave reflection distinguish between solid wood and a resin-filled crack
- ability of microwave reflection to detect cracks down to 0.5 mm in width
- ability of microwave reflection to predict the radial width and longitudinal length of any resin shakes (cracks) in a log - i.e. map the extent of a resin crack in a log (some indication from the trial that this is possible)
- ability of microwave reflection to consistently separate knots from resin defects (either cracks or resin flooded wood).

To test this fully, the CT-scanned log reference sample would be provided to Keam Holdem and their microwave scanning results would be subsequently compared to the CT data. All further microwave work would need to be undertaken using an air-gap of at least 40mm from the log surface to the sensors and the maximum practicable measurement distance will need to be determined. This test would primarily need to pass the sensitivity/detection tasks in the dot points above while demonstrating an understanding of the impact of throughput speed on the quality of outcomes. Given that there is an orientation dependence related to effect of internal structure on microwave polarisation, there is also a need to establish how many transducers/measurement positions are required to generate reliable results.

To obtain serious interest from an industrial x-ray manufacturer to develop a CT scanner the production of a business case that incorporates a much broader forest industry base than the current study of resin defects in pines is required. Other areas of need for internal log scanning would include:

(i) Australian and South American hardwood plantations initially planted for pulp but now earmarked for use as sawlogs
(ii) Certification of premium pruned radiata pine butt logs for high quality clear wood production of veneer and sawn products
(iii) Resin defects in southern pine plantations in Australia and South Africa and in radiata pine plantations in Australia, New Zealand and Chile
(iv) Knot detection and processing optimization of sawlogs and veneer from Australian hardwood plantations
(v) Premium recovery of clear wood products from European and North American cabinet wood species, and
(vi) Certification of premium pruned hoop pine butt logs for high quality clear wood production of veneer and sawn products.
2.7 Conclusion
The scanning techniques of x-ray CT and microwave reflection represent proven and potentially viable log scanning methods, respectively.

If the microwave technique is to be explored in exhaustive detail in a proof-of-concept project, this project would ideally be a joint venture between an industry consortium of interested parties and Keam Holdem Associates Ltd. The outcome of this project would help to clarify whether this technology can be realistically considered in a business case examining the economic viability of internal log scanning.

Internal log scanning is unlikely to attract interest from technology manufacturers to produce commercial prototypes unless a credible whole of forest industry business case is developed and supported. This will require a close collaboration between forest industry R&D bodies (e.g. FWPRDC, WQI) and a committed processor consortium.

2.8 Acknowledgements
Log samples supplied by Weyerhaeuser Australia, Caboolture and sampled with assistance from Greg Levinge (Weyerhaeuser). Terry Copley (DPI&F) co-ordinated the collection, storage, phytosanitary treatment, quarantine inspection (AQIS) and shipping of all log samples.

The work and collaboration of the technology providers, who completed the scanning work for this milestone, is gratefully acknowledged. Dr. John Davis undertook direct X-ray Digital Radiography and X-ray Helical Computed Tomography. Post-scanning, logs for the latter work were sawn at DPI&F’s Salisbury Research Centre by Eric Littee, Martin Davies and Terry Copley. Ms Gloria Vega, Applications Engineer with Keam Holdem Associates Ltd. (New Zealand), used Low Power Microwave Reflectance to scan the samples provided. Follow-up information has been provided by Nigel Greig, Research & Marketing Manager, Keam Holdem, who has also participated in very useful email and phone conference discussions to improve our understanding of the potential of this technology. Dr Philip Steele supervised a team at Mississippi State University (Jerome Cooper, Adam Harris and Brian Mitchell), which undertook scanning with electrical impedance tomography technology using their patented Through-Log Density Detector.
3. PREDICTING THE EFFECT OF RESIN DEFECT ON SLASH PINE LUMBER RECOVERY AND VALUE

3.1 Summary
This study sought to identify, describe and quantify visible log end resin characteristics to predict:

- the severity of internal resin defect in logs of slash pine;
- the effect of resin defect on sawn lumber recovery; and
- the effect of resin on overall recovered product value.

105 logs were selected for the study on the basis of exhibiting a severity range of visible resin defects on the cut end of the logs. Each log was classified into one of three severity resin classes and its shape and degree of resin was assessed and recorded prior to sawing. All the boards derived from sawing were uniquely tagged for identification purposes and referenced back to the sawlog, then assessed for resin defect in green form and again after drying, dressing and mechanical grading. Using the SAS (1990) statistical package the log and tagged board data was used to determine lumber grade recovery by log.

With the collated data, SAS STAT was used to generate correlations and algorithms in an attempt to determine how lumber grade, recovery and product value were affected by resin defects. SAS also indicated what relationships may exist between the severity range of visible resin defects, lumber grade, and recovery and product value.

Key study results were as follows:

- There was surprisingly little difference in lumber grade and recovery between selected resin classes. The anticipated result of increased severity range of visible resin defects inferring lower lumber recovery and lower lumber grade was not clearly evident.
- Use of resin defect class derived from resin defect visible on log ends was unable to provide a significant prediction of the effect of resin defect on lumber grade, volume and value.
- The best predictors of lumber grade were log sound wave velocity (SWV) and density, with LED and sweep also contributing.
- None of the log and board measurements (in either green or dry state) of resin defects provided an acceptable prediction of the effect of resin defect on lumber recovery and value.
- Failure to predict the effect of resin defect from external characteristics underlines the need for a cost effective log internal scanning technology.
- Failure to predict the effect of resin defect from external characteristics underlines the need for an alternative mechanical breakdown technology to recognize the upset conditions when sawing caused by resin shakes. An example; the main issue caused by resin shakes when band sawing is the clogging of the saw gullet with resin and sawdust, slowing the blade, increasing saw tension which frequently causes the saw to dive and or break. A mechanical means of detecting the increase in tension, the possible application of a lubricant such as diesel once the tension increases could reduce the severity of the upset condition.
Whereas quality logs processed at Caboolture could normally expect approximately 39% greenmill recovery from use of standard patterns for these resin affected sawlogs the overall recovery was only 36.6%. After drying, dressing and docking recovery dropped to 30.6%. Virtually all of the lumber recovery loss from green to dry dressed form was attributable to the worsening resin shake.

It was concluded that resin defect has a major effect on sawmilling returns and this needs to be reflected in pricing of logs containing resin defects.

3.2 Introduction
The occurrence and severity of resin defects in Queensland grown plantation slash pine varies considerably with environment and within stems. The economic consequences of resin defects are significant as they are a major cause of lost recovery and sawn product rejection for solid wood processors in Queensland and can result in shifts in market preference to alternative products. Resin shake is the major cause of lost recovery and sawn product rejection for solid wood processors but the presence of resin streaks also impacts on sawn, veneer and reconstituted products. The presence of resin defects also creates shifts in market preference to alternative products; both other wood resources and non-wood products.

The economic consequences of resin defects are highly significant. The cost to Queensland forest industry processors of rejecting resin defect affected wood and using it as fuel, or chipping it to sell as a low value input to reconstituted wood products, is estimated to be at least $4 to $5 million/annum based on processor feedback. Resin shake normally affects about 2% of green off saw (GOS) recovery from good sites but sawn board rejection rates are typically 4 to 5% for Weyerhaeuser Australia and Hyne and Son and this level can exceed 40% from severely affected sites.

The only current opportunity for a sawyer to assess the presence and severity of resin defect at primary log breakdown is from what appears on the ends of a log as it is presented and oriented at the breakdown saw. Therefore, this study was developed to capture detailed descriptions of resin defect on log ends and relate these to the presence and severity of resin defects in the recovered structural timber sawn from the study logs. The aim was to produce a set of guidelines to define log end resin defect criteria that could reliably identify sawlogs with uneconomically severe levels of resin defect for structural timber recovery. Previous sawing studies summarised below were based on sawing to board products to maximise the impact of resin defects on board grades and provide results of limited utility to the current structural timber study.

3.3 Previous Queensland southern pine sawing studies
In a previous Caribbean pine sawing study carried out by DPI & F timber researchers and reported by Palmer (1993) the proportion of board recovery downgraded due to resin defect/s predicted by resin defect on log ends was modest \((r^2 =0.31)\). A study of two Caribbean pine compartments in the Fraser Coast resource, 9A Tallegalla and 34A Tuan South, was commenced in 1985. All study trees were increment cored at 300mm and 1000 mm above ground and resin presence in the core noted and measured. A total of 129 trees were selected for study and 72 of these were randomly selected for felling/sawing with the rest marked and felled in 1993 to quantify the rate of development of resin defect development over time (Palmer, 1993).
The study logs were crosscut to 2.4m lengths and sawn to 25x50mm boards at the Salisbury Research Centre with every log end displaying resin defects photographed for image analysis quantification of the proportional area of the defect. An index of the irregularity of the resin defect pattern on a log cross-section was developed as a function of the area of resin impregnation in a path or multiple patches and its corresponding total circumference, as follows:

$$I = \frac{t_p^2}{(t_a \times 4\pi)}$$

Where $I$ = Irregularity Index
$t_p$ = Total perimeter length of resin defect patches (mm)
$t_a$ = Total area of resin defect patches (mm$^2$)
and $\pi = \frac{22}{7}$

This index was designed to produce a value of one for a perfectly circular resin impregnation patch and to increase with increasing irregularity, such as in a highly developed star-shaped resin defect pattern.

The best model ($r^2 = 0.309$) developed from this sawing study to predict the proportion of volume recovery of boards downgraded due to resin defect/s was:

$$R = 11.61 + 1.602h + 0.627i + 0.719r$$

Where $R$ = % volume recovery of boards downgraded due to resin
$h$ = heartwood area (on log small end)
$I$ = mean resin irregularity index (mean of small and large ends)
$r$ = mean % area of resin impregnation (mean of small and large ends).

The boards were graded to board grade criteria in AS 1781- 1975: Sawn Boards from Australian Grown Conifers (Softwoods).

A plot of the percentage length of increment core impregnated by resin against the proportion of volume recovery downgraded due to resin defect/s did not produce any useful relationship. Approximately half of the cores did not contain resin impregnation but were from trees that had between 1% and 35% of their volume of recovered boards downgraded due to resin defects.

The follow-up sawing study in 1993 revealed that the proportion of boards downgraded by resin defects was not significantly different and that knot defects were the primary cause of degrade in the older trees.

The earliest study undertaken by Smith (1965) examined 70 slash pine logs from Passchendaele and Beerburrum sawn too board products (25mm down to 15mm thickness) and concluded that:

- shakes reduce recovery by approximately 20% compared to logs free of shake;
- the extent of resin streak and shake was less in pruned stem sections compared to unpruned, although both defects were observed in both pruned and unpruned stems;
- the most extensive resin streaking was associated with large, steeply-angled live branches; and
- incidence of shakes and streaks was highest in the upper stem levels of older unpruned trees (study material was sourced from early to late thinnings age stands from 13 to 29-years-old).
A follow up study in 1969 sampled 81 trees from 30 to 38-years-old, of which 19 had been pruned. The sample was selected on branch characteristics in the lower third of the green crown to compare large diameter steep-angled and flat–angled branch habit to small diameter steep and flat angled branches. This study concluded (Smith, 1969):

- the highest incidence of resin streaking was found in trees with steep branch angles, small branch diameters and low crown length to total height ratios
- no difference in findings between pruned and unpruned stems.

Smith suggested that this higher streaking incidence in trees with small branches was associated with more prolific branching and hence a higher number of knots (based on a significant correlation between number of branches and average branch diameter of \( r = -0.338 \)). He also speculated that the crown length to total height ratio has a negative relationship with form point and that trees with higher form points are subject to greater bending stresses from wind. (Note: A tree’s form point approximates the centre of gravity of its crown).

### 3.4 Study objectives

1. Compare the profitability of lumber extracted from Beerburrum sawlogs that were selected to include a severity range of log resin defects.
2. Determine key external log indicators which could be used in the bush during log makeup in order to determine at which level the severity of resin defect reaches the point that makes processing uneconomic.
3. Determine what volumes and machine grades are recovered from the cutting and processing of resin affected logs of slash pine using standard Weyerhaeuser Australia procedures.
4. Determine what Weyerhaeuser and other sawmillers would be prepared to pay for similar resin affected stems.

### 3.5 Procedure

#### 3.5.1 Background

The intention during sawlog selection was to restrict sawlog size to within a specific mid-range size in order to reduce the number saw set changes required during sawing. In using this selection strategy it became evident that the population of sawlogs with resin steaks and flooding on the ends was limited which meant it required many trees to be harvested to obtain an appropriate log sample. Therefore the range of sawlogs SED had to be widened to include 20-45 cm SED.

A further aim was to select equal numbers of sawlogs from each resin severity class (i.e. 1 low, 2 medium, 3 severe). Again, this strategy was very difficult to achieve and to obtain the recommended population of 100 sawlogs necessitated harvesting to move to three different forest block locations. The use of three blocks may have inadvertently reduced the likelihood of significant correlations in the subsequent predictive modeling.

Table 1 summarizes harvested stand details for the three Beerburrum blocks used in the study.
Table 1. Test stand details

<table>
<thead>
<tr>
<th>Block name</th>
<th>Average Stem Vol.@CF</th>
<th>Soil Type</th>
<th>Pred Dom Ht @ C/fall</th>
<th>Initial Stocking</th>
<th>Final Stocking</th>
<th>Average Rainfall</th>
<th>Harvesting</th>
</tr>
</thead>
<tbody>
<tr>
<td>59 BlueGum</td>
<td>0.716 m³</td>
<td>Gleyed Podzolic</td>
<td>26 m</td>
<td>1100 s/ha</td>
<td>350 s/ha</td>
<td>1100 mm</td>
<td>Wet Area Category, accessed during winter by mechanical harvesting equipment</td>
</tr>
<tr>
<td>27 Coochin</td>
<td>0.656 m³</td>
<td>Gleyed Podzolic</td>
<td>26 m</td>
<td>1100 s/ha</td>
<td>350 s/ha</td>
<td>1100 mm</td>
<td>Wet Area Category, accessed during winter by mechanical harvesting equipment</td>
</tr>
<tr>
<td>14 Black Swamp</td>
<td>0.896 m³</td>
<td>Yellow Podzolic</td>
<td>27 m</td>
<td>1100 s/ha</td>
<td>350 s/ha</td>
<td>1100 mm</td>
<td>Wet Area Category, accessed during winter by mechanical harvesting equipment</td>
</tr>
</tbody>
</table>

3.5.2 Tree and log selection

The Slash pine test trees were selected under normal felling conditions with test stems being selected on the basis of resin defect present on the large end of the cut stem. The felled stems were snigged to roadside for further examination and processing into sawlogs. As mentioned problems arose in harvesting due to the low incidence of suitable resin affected stems, with hundreds of stems needing to be felled and snigged in order to produce a suitable sawlog population for the study. The initial aim was to use all of the logs in each selected stem and to track their log height class in each stem. However variability of resin defect up the stem meant that this was not possible because many defect free logs would have been included. Consequently rather than all logs within a stem only those with visible resin defect included being tagged with a number and classified under resin class 1, 2 or 3 classes (low/med/severe). The resin classes used were as follows:

Resin Class 1:
- A shake within 0-40% of radius
- Shake contained within 0%-16% of basal area
- Resin Streaking or flooding contained within 50% of diameter

Resin Class 2:
- 1 or more shakes within 40%-50% of radius
- Shake contained within 16%-25% of basal area
- Resin Streaking or flooding effecting 75% of diameter

Resin Class 3:
- 2 or more shakes greater than 50% of radius
- Shake contained greater than 25% of basal area
- Resin Streaking or flooding effecting 100% of diameter

The 105 logs selected were sorted and colour-coded with the following data being to collected on each log:

- Operation Type: Clearfell
- Log position (butt/upper): Butt – first sawlog; between base of the tree and first sawlog
- Log acoustic (SWV): SWV – Sound Wave Velocity using Hitman, a resonance tool
- Branch ang (BIXANG): BIXANG– the angle of the branch to the sawn surface
- Resin class: 1, 2, 3 class as outlined above
- Density: Basic density from a log end cross section
3.5.3 Sawmilling and processing

- All logs were passed through a Komac log scanner and assessed for LED, SED, taper, length, volume and sweep.
- Sawlogs were sawn using standard Weyerhaeuser patterns that produced predominantly 35 mm thick scantling products. Table 2 summarizes the lumber sizes recovered.
- Green scantling lumber was sorted and stacked by size, length and heart-in (HI) and non heart-in or Run of Stack (ROS)
- Each board end was tagged for board/log number and visual assessed for resin defect type prior to kiln drying. The resin defect was measured for size and position within the board (also enabled determination of the volume effected by resin defect).
- The timber was high temperature dried at 140/90˚C followed by final steaming at 100˚C/100% relative humidity.
- After planning, scantling boards were mechanically graded using a Metriguard CLT.
- Board material (i.e. 25 mm thickness) was collected and bundled for visual grading in green form (only the scantling lumber was tracked through the planer and mechanical grader).
  - Board/log ID number, trim and grade marks were recorded for all scantling and 25 mm thick boards.
  - The board data were then aggregated back into individual logs

<table>
<thead>
<tr>
<th>Visually Graded Boards</th>
<th>Machine Graded Boards</th>
</tr>
</thead>
<tbody>
<tr>
<td>70x19 mm</td>
<td>70x35 mm</td>
</tr>
<tr>
<td>90x19 mm</td>
<td>90x35 mm</td>
</tr>
<tr>
<td>140x19 mm</td>
<td>120x35 mm</td>
</tr>
<tr>
<td>190 mmx19 mm</td>
<td>140x35 mm (Split to 2@70x35 mm)</td>
</tr>
<tr>
<td>240 mmx19 mm</td>
<td>190x35 mm (Split to 2@90x35 mm)</td>
</tr>
</tbody>
</table>

3.5.4 Data collection from boards

The following data was collected from all boards with each board/log number being recorded to enable the analysis by log and log resin class.

- **Green Sawn Stage**
  - Length of each resin split in each board
  - Maximum width of each resin split
  - Volume impacted by defect type
  - Number of resin shakes in each board
  - Total length of board effected by resin shake
  - Number of distinct branches with associated resin streak
  - Branch angle
  - Length of wane requiring docking
  - Total length of acceptable lumber contained in each board
  - Presence of pith/heart-in

- **Dry Dressed Stage**
  - Resin shake length and width as well as the total board length effected by resin shake were reassessed
  - Stress grade of each scantling board i.e. MGP10, MGP12, MGP15, F4 or Merchantable was recorded
  - Total recovered length of board
3.6 Results

3.6.1 Part I: Relationship between resin defect class and scantling grade

There are two steps in determining a relationship between visual sawlog resin class and machine graded pine (MGP) grade recovery.

**Step 1** Build a relationship between MGP10 & better and the predictive variables.

The variables which were chosen for the Step 1 prediction development included:

- log basic density,
- log sound wave velocity (SWV)
- branch angle (BIXAng),
- longest shake in each board (LongestSh),
- width of worst shake in each board (WidthSh),
- total length board effected by shake (TotalLenSh),
- maximum length shake extends from pith towards bark (PithFarSh),
- total number of board faces affected by shake (BrdShNo),
- total number of shakes (ShNo),
- number of board cross section affected by resin/shake on the log SED (CountBrdSh),
- proportion effected by resin defect (Defect total)

**Step 2** Given that Step 1 is satisfied, then develop a relationship between sawmill MGP10 & better and sawmill cost and return/profitability.

The development of the second relationship is heavily reliant on successful development of the first relationship (without the relationship from the Step 1 there is limited likelihood of a successfully developing the Step 2 relationship.

The SAS STAT (SAS, 1990) statistical package was used for the analysis.

In Step 1 the logical process used in developing the relationship was that the greater the visual resin severity evident on the end of a log, the lower would be the recovery of MGP10 & better lumber arising after mechanical grading. On this basis for the resin defect analysis it was decided to use the maximum severity of each type of visible resin defect present in each board.

Table 3a summarizes the Pearson correlation data and levels of significance in predicting yield of MGP10 & better from individual visible resin defects and Table 3b the MGP10 & better prediction significance levels from log characteristics such as diameter, sweep, taper, resin class and volume of log affected by resin defect.

**Table 3a. Summary of results correlation analysis between individual resin defects and MGP10 & better recovery**

<table>
<thead>
<tr>
<th>Variable</th>
<th>BIX Angle</th>
<th>Longst Shake</th>
<th>Width Shake</th>
<th>TotalLen Shake</th>
<th>PithFarSh</th>
<th>BrdShNo</th>
<th>Shake No</th>
<th>CountBrd Shake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation¹</td>
<td>0.088</td>
<td>–0.0493</td>
<td>0.0304</td>
<td>–0.0651</td>
<td>–0.0923</td>
<td>–0.1486</td>
<td>0.0125</td>
<td>–0.1941</td>
</tr>
<tr>
<td>2-tail T value²</td>
<td>0.3699</td>
<td>0.6299</td>
<td>0.7659</td>
<td>0.5244</td>
<td>0.3662</td>
<td>0.1302</td>
<td>0.8991</td>
<td>0.0472</td>
</tr>
</tbody>
</table>

¹ Pearson correlation coefficient. NB low value indicates poor correlation
² 2-tailed T value significance. NB a high number indicating a low number amount of the population data set can contribute to a predictive model for MGP10 & better.
Table 3b. Summary of results correlation analysis between individual log characteristics and MGP10 & better recovery

<table>
<thead>
<tr>
<th>Variable</th>
<th>SED</th>
<th>LED</th>
<th>Svel</th>
<th>Resin Class</th>
<th>Sweep</th>
<th>Taper</th>
<th>Density</th>
<th>Defect Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correlation¹</td>
<td>–0.1910</td>
<td>–0.1708</td>
<td>0.33349</td>
<td>–0.14902</td>
<td>–0.04915</td>
<td>0.27012</td>
<td>–0.17076</td>
<td></td>
</tr>
<tr>
<td>2-tail T value²</td>
<td>0.0509</td>
<td>0.0814</td>
<td>0.0005</td>
<td>0.1292</td>
<td>0.6186</td>
<td>0.0053</td>
<td>0.0816</td>
<td></td>
</tr>
<tr>
<td>No of samples</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td>105</td>
<td></td>
</tr>
</tbody>
</table>

¹ Pearson correlation coefficient. NB a low value indicates poor correlation
² 2-tailed T value significance. NB a high number indicating a low number amount of the population data set can contribute to a predictive model for MGP10 & better.

All of the visible resin defect variables used in Table 3a gave very poor predictions of MGP10 & better with the highest correlation of only –0.194 coming from the volume of log affected by resin defect.

Numerous previous studies (eg Roper et al., 2004) have highlighted the potential for use of log sound wave velocity and density to predict lumber grade recovery thus it is not unexpected that for the current study the most significant individual log variables for predicting MGP10 & better were sound wave velocity (correlation coefficient of $r^2 =0.33349$ and significance of 0.0005) and density correlation coefficient $r^2 =0.27012$ and significant variable 0.0053). Resin class appeared to have very little influence over MGP10 & better recovery. Figures 1-12 show graphically the poor relationship between individual prediction variables and MGP10 & better grade recovery.
**Figure 1.** Relationship between branch angle & MGP10+

**Figure 2.** Relationship between number of board shakes & MGP10+
Figure 3. Effect of density on MGP10+

Figure 4. Effect of longest resin shake on MGP10+
**Figure 5.** Effect of number faces with resin shakes on MGP10+

**Figure 6.** Effect of number of resin shakes on MGP10+
Figure 7. Effect of log resin class on MGP10+

Figure 8. Effect log sort SED on MGP10+

Figure 9. Effect of log SWV on MGP10+

Figure 10. Effect proportion affected by all resin defects on MGP10+
Figure 11. Effect of total length of board resin shake on MGP10+

Figure 12. Effect of board maximum shake width on MGP10+
As part of further analysis, multivariate techniques were used in an attempt to improve the prediction of the effect of resin defect on lumber recovery and lumber value. Table 4 shows the correlation coefficients for a range of predictions for mechanically graded lumber recovery. Note the predictions in the bottom three rows attempt to predict grade recovery using only resin defect variables as distinct from the other predictions which have also included non-resin variables such as density and log sound wave velocity. Figure 13 illustrates a multivariate prediction of MGP12 and better recovery using both log and resin defect variables.

![Vertical Bar Chart Showing Percent Residual vs Independent Variables](image)

**Figure 13.** Multivariate prediction of M12 & better recovery percentage from log LED, sweep, resin class, density and SWV

As with the predictions from individual variables, the multiple predictions with the highest correlation coefficients are those that included density and SWV. The correlation coefficients are higher for MGP15 than MGP10, which is probably more due to the effect of higher wood density, acoustic properties and smaller knots in the MGP15 than to the presence of less resin defect.

When the resin defect variables alone (three predictions at bottom of Table 4) were considered they were only able to provide a maximum $r^2$ of 0.2. The correlation coefficient decreased with lower overall grade, that is, it decreased from MGP15 down to MGP10 & better. Hence, the ability to predict in-grade recovery (MGP10 & better) using only resin defect variables is very poor ($r^2 = 0.05$).
Table 4. Multivariate predictions of lumber grade recovery

<table>
<thead>
<tr>
<th>Variables in Model</th>
<th>Overall Recovery (m³)</th>
<th>Adjusted r²</th>
<th>Root MSE</th>
<th>MGP15 (%)</th>
<th>Adjusted r²</th>
<th>Root MSE</th>
<th>MGP12 (%)</th>
<th>Adjusted r²</th>
<th>Root MSE</th>
<th>MGP10 (%)</th>
<th>Adjusted r²</th>
<th>Root MSE</th>
<th>MGP12 &amp; Better (%)</th>
<th>Adjusted r²</th>
<th>Root MSE</th>
<th>MGP10 &amp; Better (%)</th>
<th>Adjusted r²</th>
<th>Root MSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SED, Sweep, Density, BIXANG, BrdShNo</td>
<td>0.625</td>
<td>0.6048</td>
<td>0.0225</td>
<td>0.6382</td>
<td>0.6146</td>
<td>0.0242</td>
<td>0.7463</td>
<td>0.7218</td>
<td>0.0250</td>
<td>0.3790</td>
<td>0.3598</td>
<td>0.0260</td>
<td>0.5513</td>
<td>0.5333</td>
<td>0.0270</td>
<td>0.6285</td>
<td>0.6096</td>
<td>0.0280</td>
</tr>
<tr>
<td>LED, Sweep ResinClass Density LEDSvel</td>
<td>0.575</td>
<td>0.5519</td>
<td>0.0212</td>
<td>0.7230</td>
<td>0.7068</td>
<td>0.0228</td>
<td>0.8765</td>
<td>0.8616</td>
<td>0.0240</td>
<td>0.3790</td>
<td>0.3598</td>
<td>0.0260</td>
<td>0.5513</td>
<td>0.5333</td>
<td>0.0270</td>
<td>0.6285</td>
<td>0.6096</td>
<td>0.0280</td>
</tr>
<tr>
<td>Density BIXAng WidthSh</td>
<td>0.1946</td>
<td>0.1689</td>
<td>17.5227</td>
<td>0.2285</td>
<td>0.1866</td>
<td>12.0747</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
</tr>
<tr>
<td>SED Taper ResinClass LEDSvel LongestSh</td>
<td>0.3304</td>
<td>0.2940</td>
<td>18.2681</td>
<td>0.2285</td>
<td>0.1866</td>
<td>12.0747</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
</tr>
<tr>
<td>LEDSvel, Svel, BIXANG, TotalLenSh, ShNo, CountBrdSh</td>
<td>0.4782</td>
<td>0.4518</td>
<td>18.4695</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
</tr>
<tr>
<td>LongestSh, PithFarSh, CountBrdSh</td>
<td>0.0875</td>
<td>0.0584</td>
<td>23.34</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
</tr>
<tr>
<td>ResinClass, PithFarSh, CountBrdSh</td>
<td>0.0496</td>
<td>0.0296</td>
<td>13.19</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
<td>0.2014</td>
<td>0.1674</td>
<td>25.92</td>
</tr>
</tbody>
</table>

Unpublished radiata pine data from Green Triangle Forest Products (GTFP) return to sawlog studies have indicated that a correlation coefficient of at least 0.6 is necessary to provide a model suitable for the prediction of lumber grade from stems and logs (personal communication, Selleck and Haslett, GTFP). With the exception of overall recovery of utilizable boards, none of the multivariate models were able to provide an adequate prediction of the effect of resin on final dry grade recovery.

Clearly the failure to generate meaningful predictions of the effect of resin defect on grade is very disappointing. One could speculate that the strength of the correlations could have been improved by maintaining the integrity of the stem data and assessing all of the logs in each stem rather than selecting and assessing individual resin affected sawlogs during harvesting. However, a more intensive full stem assessment was well beyond the scope of this study because it would have more than tripled the number of logs requiring assessment. Additionally, for this prediction to be of practical use it must be able to be randomly applied to any log presented for assessment in the log yard. The approach used emulates this latter scenario and is a demonstrable failure. Therefore, on balance we consider it unlikely that restricting the tree selection to one site and tracking all logs in each stem would have significantly improved our predictions. We believe that the work in this study has once again demonstrated and emphasized the variability of resin defect and how difficult it is to accurately predict its impact from external log characteristics.

3.6.2 Part II: Quantification of recovery and grade from sawing logs containing resin defects

Table 5 and Figure 14 show board volume yields for each log resin class and percentage yields at various stages during processing. Key points arising from Table 5 and Figure 14 are:

- The Komac prediction of a total recovery of 43.7% aligned closely to the 44.0% achieved but, after docking for wane and resin defect the recovery dropped to only 36.6% (a reduction of nearly 17%).
- The recovery of docked green 35 mm scantling was 34% but after drying, planing and docking this fell to 30.6%. Thus compared to the green docked state the combination of the exposure and the worsening of resin defects during drying and planing caused a further 3.4% loss of recovery; that is, a further loss of 10% in dry mill recovery.
- We had expected down-grade and lumber recovery to decrease with increased resin defect from Resin Class 1 to 3. However, Table 5 and Figure 14 both also show that all three log resin classes (classes were based on the severity of resin defect visible on
log ends) exhibited similar recoveries through-out processing to the final dry dressed state.

- That there was only a 1.9% difference in dry 35 mm recovery between log of resin class 1 and class 3, despite class 3 displaying substantially more resin defect on the log ends. This highlights underlines that log end resin defect indicators are not able to provide a suitable prediction of the recovery of acceptable lumber.

- Caboolture sawmill generally achieves a greenmill recovery of about 39% (dry dress equivalents) but for these resin affected logs the greenmill recovery was 34%, which represents a negative cost variation of approximately 15% on the recovered product.

Table 5. Sawn lumber (dry dressed equivalents) recovery by log end resin class at different stages during a manufacturing processing

<table>
<thead>
<tr>
<th>Volume (m³)</th>
<th>Resin-1</th>
<th>Resin-2</th>
<th>Resin-3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>KOMAC predicted recovery</td>
<td>4.245</td>
<td>3.948</td>
<td>4.081</td>
<td>12.274</td>
</tr>
<tr>
<td>Green 19&amp; 35 mm recovery (before rejects &amp; docking)</td>
<td>4.245</td>
<td>4.005</td>
<td>4.103</td>
<td>12.352</td>
</tr>
<tr>
<td>Green 19&amp; 35 mm recovery (after rejects &amp; docking)</td>
<td>3.541</td>
<td>3.464</td>
<td>3.285</td>
<td>10.290</td>
</tr>
<tr>
<td>Green 35mm recovery (before reject &amp; docking)</td>
<td>3.933</td>
<td>3.735</td>
<td>3.906</td>
<td>11.574</td>
</tr>
<tr>
<td>Green 35mm recovery (after reject &amp; docking)</td>
<td>3.253</td>
<td>3.217</td>
<td>3.095</td>
<td>9.565</td>
</tr>
<tr>
<td>Dry 35mm recovery (after reman &amp; docking)</td>
<td>2.989</td>
<td>2.895</td>
<td>2.715</td>
<td>8.599</td>
</tr>
<tr>
<td>Green 35mm recovery as a percent of log volume</td>
<td>34.0%</td>
<td>34.6%</td>
<td>33.5%</td>
<td>34.0%</td>
</tr>
<tr>
<td>Dry 35mm recovery as a percent of log volume</td>
<td>31.3%</td>
<td>31.1%</td>
<td>29.4%</td>
<td>30.6%</td>
</tr>
</tbody>
</table>

Figure 14. Sawn lumber recovery by log end resin class

The unexpected small difference in recovery between the three log end resin classes further supports why we have been unable to derive significant correlations, not only between log end visible resin defects but also from actual lumber resin defects such as longest shake or widest shake.
When the study grade and recovery data were compared to general Weyerhaeuser Caboolture production data for 19 and 35 mm end sections obtained from standard Weyerhaeuser Australia scantling cutting patterns two points were apparent:

1. There was a difference in the recovery from the current resin affected logs versus that from normal run of bush logs sawn at Caboolture. The Caboolture drymill (i.e. post-planing) normally recovers approximately 36% from run-of-bush logs but the current resin-affected logs produced only 30% dried dressed recovery. A drop in recovery of this size represents approximately a $2 million variation on value adding sawmill performance.

2. Normally Caboolture achieves approximately 91% recovery of MGP10 & better and when only the resin free wood from the current study is considered a recovery of 90% was achieved (see bottom row Table 6).

Table 6 confirms how a sawmill refines the sawn timber by segregating out the defective component and increases the grade albeit at the expense of recovery. It is clear that resin-flooded timber significantly impacts sawmill volume recovery, however, in this study it did not significantly impact the grade yield derived from the remaining timber. The sawmill process has adapted to the resource to extract as much lumber volume and lumber grade as possible, which drives value. However, a negative impact of reduced recovery is that direct and indirect costs are incurred as a consequence of the reduced volume of in-grade produced.

A range of somewhat hidden but nonetheless very significant further costs are incurred, as explained earlier in the introduction, from the damage created by resin effecting bandsaw stability.
Table 6. Recovery (%) by resin class at different processing stages

<table>
<thead>
<tr>
<th></th>
<th>RESIN CLASS 1</th>
<th></th>
<th>RESIN CLASS 2</th>
<th></th>
<th>RESIN CLASS 3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MGP10</td>
<td>MGP12</td>
<td>MGP15</td>
<td>F4</td>
<td>Utility</td>
<td>Webb</td>
</tr>
<tr>
<td>Green Log Volume</td>
<td>6.8</td>
<td>7.8</td>
<td>11.4</td>
<td>2.6</td>
<td>1.1</td>
<td>1.6</td>
</tr>
<tr>
<td>Before Rejects &amp; Docking</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green 19 &amp; 35 mm Recovery</td>
<td>15.3</td>
<td>17.6</td>
<td>25.6</td>
<td>5.7</td>
<td>2.5</td>
<td>3.6</td>
</tr>
<tr>
<td>Green 35 mm Recovery</td>
<td>16.5</td>
<td>19.0</td>
<td>27.6</td>
<td>6.2</td>
<td>2.7</td>
<td>3.9</td>
</tr>
<tr>
<td>After Rejects &amp; Docking</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green 19 &amp; 35 mm Recovery</td>
<td>18.3</td>
<td>21.1</td>
<td>30.7</td>
<td>6.9</td>
<td>3.0</td>
<td>4.4</td>
</tr>
<tr>
<td>Green Recovery</td>
<td>20.0</td>
<td>23.0</td>
<td>33.4</td>
<td>7.5</td>
<td>3.3</td>
<td>4.7</td>
</tr>
<tr>
<td>After Remanufacturing &amp; Docking</td>
<td>21.7</td>
<td>25.0</td>
<td>36.4</td>
<td>8.2</td>
<td>3.6</td>
<td>5.2</td>
</tr>
</tbody>
</table>

Note: calculations are made in dry dress volume size.
3.7  Conclusions

Log resin class based on external visible resin characteristics on log ends is unable to provide a useful indication of effect of resin on sawn grade and recovery. With less than 5% of the variation in MGP10 & better graded recovery explained by log end resin defect variables \( r^2 = 0.0496 \) there is no point in extending the study to attempt to improve the predictive relationship to a practically useful level of prediction. However, resin defect reduces sawn lumber recovery and value and causes additional processing costs to be incurred due to bandsaw failures and other mill plant maintenance issues. It therefore needs to be considered in determining log pricing structures.

This failure to predict the effect of resin defect from externally visible log-end features further underlines the need for an internal defect scanning system to allow the segregation of unprofitable sawlogs before unrecoverable processing costs are spent on them. X-ray technologies are well advanced in Sweden as a research tool (Grundberg et al., 2002; Grundberg and Grönlund, 1997; Sanberg, 2002; Sepúlveda et al., 2002) and are being developed in Canada (Alkan, 2002) and there are reports of industrial use of the Microtec Tomo Log scanner in Chile (refer to web-site www.microtec.org). Microtec technical data claims the TomoLog system can detect shakes in logs of up to 50cm diameter at an operational stock feed rate of up to 120m/minute. Our x-ray scanning results show that resin defect detection requires the CT modality and the capability of the Tomo Log system for this purpose is unknown.

The internal log scanning technology test conducted as part of this project clearly identified x-ray computed tomography (x-ray CT scanning) as being very effective at identifying the extent and severity of resin defects within a log. It is an advanced and mature technology poised for implementation in forestry sawmilling.

3.8  References


4. PROJECT CONCLUSION

4.1 Introduction
This study has conclusively found that the relative economic impact on sawn structural timber products due to the resin defect structure within Slash Pine logs cannot be predicted by any external characteristics. Of the four internal scanning techniques investigated, only x-ray CT produced specific and quantitative structural information that would potentially enable the reliable classification of logs into quality classes to achieve increased value recovery and the reduction of current processing costs.

The outcomes of this project are consistent with similar investigations of softwood and hardwood species during the past 30 years (eg Australia, Canada, Sweden, USA, NZ). Where it has been found necessary to define the spatial distribution of significant quality affecting features, only x-ray digital radiography (DR) and x-ray helical computed tomography (CT) have demonstrated practical viability.

Most, if not all, of these scanning investigations employed x-ray CT in the first instance partly to determine the limits of its ability to detect and measure quality features and because it produced a rich three-dimensional data base that served as a simulation platform for the development of x-ray DR scanning of logs and stems and log processing simulation (eg Luleå University of Technology, Sweden). CT has been considered impractical because it could not meet industrial feed speed targets, the real-time automatic computer analysis of vast data sets was too complicated and technologically limited, the associated costs of CT were too high and the fastest machines that were essentially designed for medical diagnostics could not sustain industrial availability. X-ray DR is much cheaper, its performance is coherent with timber industry practice and its application is very similar to advanced external log scanning technology that is now used world wide. However, x-ray DR utility is probably limited to certain softwood species and it cannot deliver the precise unambiguous 3D information that would make internal scanning viable. Only CT has this unique ability.

Where investigators have shown CT to be the only technique to reveal the quality features of commercial value, few have pursued the practicable application of what is now a mature and relatively robust technology. Instead, most researchers over the past 20 years have focused on sophisticated computer analysis techniques for automatic internal feature definition and the simulation of breakdown optimization based on data acquired from medical scanners or from the painstaking physical breakdown of logs. Consequently, much of the research activity related to CT log scanning has not been useful in advancing a business case for the commercial implementation of CT.

In this final chapter reasons for this implementation failure will be addressed and a possible strategy to determine whether the adaptation of CT technology by the timber industry has practical and commercial merit will be proposed.

4.2 Is CT a viable technology for log scanning?
Internal log scanning only makes sense when exhaustive analysis clearly demonstrates that there are no practical and commercial alternatives and the rewards are commercially attractive. Scanning technology such as CT is an expensive additional
cost to the log breakdown chain. To justify its introduction, it must be demonstrated that it can produce increased value recovery (volumetric and grade) and that it has the potential to influence the entire value chain.

Financial modeling of the impact of internal scanning is a first step in assessing the commercial viability of the appropriate technology. The validity of modeling rests on a number of key technology assumptions including:

- That internal scanning can detect and quantify specific internal quality information.
- Specific internal information can be automatically identified and evaluated.
- That log processing technology is coherent with the internal scanning information.
- The internal scanning system operation can satisfy throughput availability requirements.

Industrial x-ray CT log scanning is not currently commercially employed anywhere in the world. Other scanning techniques using electromagnetic radiation (x-ray DR, visible eg laser, microwaves) and acoustic testing (eg HITMAN) have found niche applications within the timber industry and mostly downstream of the headrig. X-ray DR (2-projector RemaLog X-ray, Sweden; 3-projector Microtec TomoLog, Austria) is becoming a credible industry tool for log quality sorting and, to some extent, sawing optimization. This is because it can deliver useful quality information at mill feed speeds for certain softwood species, namely Pinus sylvestris and Pinus radiata, where the log diameters are not large (Pinus sylvestris) and where features of interest (eg knot whorls, defect core) are not seriously masked by high moisture content. X-ray DR is not appropriate for slash pine for the latter reason and also because it cannot deliver the 3D information necessary for resin defect evaluation.

CT has two main advantages over projection radiography. Firstly, the inherent image contrast is at least 100 times greater than in radiography and, secondly, CT is able to “singulate” the defect/feature because the measured transmission data allows a volume reconstruction (image) of the density distribution within a log. This density reconstruction contains morphological and anatomical information that allows objective automatic computer analysis of an individual log. However, CT throughput speeds, up to 30m/min depending on scanner setup parameters and the desired quality of image information, cannot match the 120 – 200 m/min feed speed of x-ray DR. Thus the impact of CT feed speed on value recovery will be a critical factor requiring specific attention in a business modeling study.

While there are many technical issues involved in the development of a CT log scanning system, the major problem is not necessarily of a technical nature. The Microtec TomoLog x-ray scanning system grew out of extensive collaboration with Italian academic research institutes and its technical development was sponsored by a major German sawmiller (Klenk). Klenk was Microtec’s technical sponsor and preferred beta-site for a decade. The development of the TomoLog system no doubt leveraged off Microtec’s expertise in the application of advanced optical electronic scanning (eg 3D laser) to the wood processing industry. The Swedish company
RemaControl has had a similar development trajectory with its RemaLog X-ray log scanner.

In the USA, industrial x-ray CT company InVision Technologies (acquired by General Electric in 2004) sought to extend its core business of aviation security (explosives detection in airline baggage) to the timber industry via dedicated subsidiaries, WoodVision and Inovec. Inovec is a manufacturer of advanced optimization sawmill equipment. InVision had a continuing interest in this application from the mid 1980’s when it was seeking commercial opportunities beyond the aviation security market. Whilst InVision had conducted successful cooperative testing programs with a number of timber companies in the USA and Austria, it did not establish an enduring technology partnership with the timber industry to promote its proven log scanning technology. Apart from InVision, no other CT manufacturer has been persuaded that the timber industry posed an attractive market for its technology. It is our understanding that the GE-InVision technology is now fully focused on the aviation security market.

A practical realisation of CT log scanning requires a solution for a field viable product that can be fully integrated (mechanically and software wise) with a commercially attractive target application. This can only be achieved through a close and enthusiastic partnership between a technology provider and a significant player or consortium within the forest products industry provided both parties are convinced of the economic benefits.

4.3 Can CT meet the performance and cost demands of the timber industry?

Four questions are worth asking:

1. What CT systems have the fastest linear throughput speeds?
2. What is the status of CT as it might apply to the timber industry?
3. What would it cost?
4. Is CT available as a readily adaptable product?

Medical CT scanners offer the fastest linear throughput because of the extremely rapid rotation of the gantry (up to 180 RPM) and the high number of detector rows (up to 64 rows). The aperture of certain medical CT scanners is also increasing from the standard 0.7m. Since there is a fierce competition in the medical imaging field, the major manufacturers Philips, GE, Toshiba and Siemens offer similar solutions in terms of scanning speeds and modes. The linear throughput speed increases, approximately, in proportion to the gantry rotation speed and the number of rows of detectors. However, medical scanners are not technically set up for continuous (industrial) scanning. While the current capabilities of explosive detection scanners (EDS) manufactured in the USA (GE-InVision, L-3, Analogic, Reveal) are probably within the performance envelope required for log scanning, the desired performance specifications of an industrial log scanner should be determined from a modeling study that addresses the financial impact of internal log knowledge.

There is not much progress to report on the application of CT to log scanning. InVision, through its subsidiary WoodVision committed significant resources over several years (up to September 2001) to the development of a viable CT log scanner.
based on its EDS products. The InVision-WoodVision venture is probably the closest any project has come to producing a commercial CT log scanning system. This was mostly due to its unique experience in the design, construction, integration and human interface with a variety of clients within the aviation industry. The biggest concern for the application of CT technology to the wood industry is probably the relatively low availability or uptime of CT equipment. For example medical CT systems have an uptime rated at 95%, which is probably low for timber-industry equipment.

Conventional helical CT systems (mechanically rotating gantries) are following Moore's law in terms of the speed of throughput (data gathering) and imaging performance. This is not unexpected since one would expect these achievements from the hi-tech equipment anyway. However, the radiating side (x-ray tubehead, detectors and their subsystems) of the CT equipment is probably the limiting factor for its reliable application to log scanning. The X-ray tubehead and its associated modules (generator, cooling pump) must maintain continuous stable performance under constant and extreme centripetal acceleration conditions. This would need to be clarified through interaction with potential CT suppliers.

The pricing evolution of medical scanners and industrial explosive detection scanners is unknown but one could expect it to be significantly large. The price of the mechanics and the electro-mechanics (including the radiating chain) is fairly stable and the dramatic increase of detector element numbers in recent CT scanners compensates for the normal detector price reduction. The main driving factor in the price of a CT scanner for log scanning will be its “ruggedization” and integration within varied and hostile environments. A realistic price for an off-the-shelf scanning unit is estimated to be around US $1M, depending of the level of integration required.

The x-ray DR scanners allow automatic detection and definition of the defect core, sapwood-heartwood boundaries, knot whorls and a number of relevant quality parameters for certain log types. Because of the small number of projections, neither system can produce the volume detail of a CT scanner (700 projections) - Microtec claims TomoLog has CT capacity but the details are vague and appear to be commercially protected (no response to enquiries has been received). The accuracy of the defect characterization and its localization (singulation) is problematic due to the ambiguities produced by the small number of projections and the contrast limitations imposed by moisture (sapwood) within the log. It is also likely that significant improvements can be made in the following areas:

- Smooth and fast log feed mechanisms that do not vibrate the log more than the desired resolution and accuracy parameters.
- Improvement of the reliability and specificity of automatic computer data processing of x-ray data.

The former is a relative issue because the resolution and accuracy demands are dependent on the application. Both areas may require extensive R&D programs involving substantial expenditure. Similar observations apply to a CT log scanner.

At the recent IUFRO Working Party S5.01.04 workshop in New Zealand (20-27 November 2005) Arto Usenius (VTT Technical Research centre of Finland) discussed the use of tomographic software to convert data from DR X-ray sensors into a three-
He emphasised that the key R&D challenge was to define specific image capture requirements (e.g. knot size, position and shape) and then to fine-tune the data capture process so that the minimum resolution was used to reconstruct the log image to reliably provide the data capture resolution required. This latter point was the key to being able to operate at the maximum possible speed while providing useful results in a production environment and would be critical to the viability of industrial CT scanning.

In summary, the current state of CT technology suggests that it may have the capability to satisfy the performance demands of the timber industry. X-ray DR is now achieving world-wide market penetration in the softwood sector (e.g. Finland, Germany, New Zealand). CT companies involved in the explosives detection sector and possibly Microtec appear to be potential technology providers.

4.4 Commercial and technology scoping study for internal log scanning

There exists sufficient data that would allow the collaborators in this project to construct a financial model that would realistically predict the impact of internal (CT) scanning on the slash pine sector. It would be useful to extend the modelling study to areas of the Australasian softwood and hardwood industry where internal scanning is likely to have significant commercial impact. Sectors of the New Zealand forest products community have extensive knowledge the commercial and technical significance of x-ray log scanning. Therefore it would be initially prudent to consider the formation of an Australasian consortium of interest.

The modelling task will require reliable cost factor inputs related to the scanning technology. These costs are probably well known for x-ray DR (RemaControl, Microtec) but they are not readily available for CT. In any event, it will be necessary for the modelling project to demonstrate whether the appropriate internal scanning (CT/DR) is an attractive business opportunity within the context of the Australasian timber industry. It will be most important to determine if there is a commercially compelling case for CT alone. Unlike the x-ray DR systems, CT log scanners are not “off-the-shelf” products. The Australasian market for CT will be small anyway and so it will be incumbent on the project consortium to extrapolate the modelling to the international market in order to establish a proposition that would attract a CT technology provider.

There is also a view that CT log scanning should target high value, and low throughput, markets at least initially in order to establish a credibility status for the technology. This observation deserves consideration within the scope of a modelling study.

There have been many studies over the past 30 or more years that suggest significant recovery and value returns can be achieved through knowledge of the internal quality of an individual log. Most of these studies have been done either independently or at arm’s length from a cooperative technology provider. It was pointed out earlier that
most of the research work associated with the analysis and utilisation of CT log data did not address the crucial issue of whether CT scanning technology was commercially viable. Some projects attempted to address this issue (eg the Glass Log Project) but either through flawed project design, inadequate partnerships or plain naivety, the real prospect of CT log scanning has not been seriously assessed by the timber industry itself - not one CT log scanner is in routine commercial operation any where in the world!

The future for CT log scanning is essentially in the hands of the timber industry and the relevant technology providers. The CT industry, both medical and non-medical, are either manufacturers of a narrow product line or they manufacture one-off systems for a wide range of clients and they are averse to committing key personnel and resources to non-core R&D programs.

The timber industry would need to be convinced of the benefits that could flow from a major investment in internal scanning technology. To interest a technology provider in the development of a log scanner will require a compelling business case to divert attention from core business and will certainly involve a significant investment from the timber industry partner/s. Potential applications within the Australasian forest products industry may include:

- Resin defect detection for log sorting prior to sawing in slash pine and other southern yellow pine logs
- Knotty core definition in veneer and sawn clearwood logs – radiata pine, hoop pine and plantation hardwoods (eg older age NSW *E. grandis* plantings)
- Defect detection in high pruned butt logs for clearwood products (radiata pine, hoop pine and some hardwoods)

The technical feasibility of CT log scanning was demonstrated by InVision Technologies in the laboratory and at industrial beta-sites in the USA and Austria prior to 2001. However, there is no commercial CT log scanning system operating in an industrial environment anywhere. Possible reasons for this situation include:

- That either industry or independent consultants have found the technology as it existed failed to meet acceptable criteria in respect of financial, sensitivity and risk analyses. However, even if these analyses have been conducted, the results are not in the public domain. To our knowledge no serious study has been undertaken in Australia but it is likely that elements of the NZ forest products industry have an appreciation of the impact of internal log scanning using x-rays.
- That potential enduring partnerships between, researchers, technology providers and the timber industry were unsuccessful.
- That CT technology providers, of which there are probably 3 in the world with relevant experience, are reluctant to focus on applications outside their core business even if they are presented with a compelling business model.
- That even if the CT technology provider is attracted to a joint venture, it is highly likely that the timber industry partner would carry a relatively heavy financial burden, and risk, in the initial phases of the venture.
Therefore, the concept of internal log scanning using CT is no further advanced than the Glass Log Project of the mid 1990’s. Today the technology is much further advanced and represents a realistic option. In the mid 1990’s it was not known if a viable financial case could be made for internal log scanning using CT or DR. Such a study was proposed in 1996 by the FWPRDC but was never enacted. In 2005/06 we still don’t know.

4.5 Commercial feasibility study

If the FWPRDC and the Australian Forest Products industry wants to seriously evaluate the potential for industry adoption and implementation of CT scanning technology, it is recommended that consideration be given to a commercial impact study of internal log scanning within the Australasian industry. The study should also appreciate the international opportunity since the viable market for internal log scanning must be global. The study will embrace the following main areas:

- A financial cost benefit analysis
- Sensitivity analysis
- Commercial and technical risk analysis including the identification of likely technology providers and potential markets

4.5.1 Project scope

It is proposed that a consortium of interest (COI) be formed of elements of the Australasian forest products industry. The COI will determine the detailed scope of the project, source funding for the project and engage an appropriate analyst who will conduct an independent study as outlined below. The independent analyst will be qualified to develop financial models that will enable a comprehensive assessment of the commercial significance of internal log scanning. The project would require three main elements:

1. **A financial cost benefit analysis**
   This should include the development of a general business model that will enable the analysis of the financial benefits of internal scanning technology including:
   - Impact by region/state or species
   - The ability to improve value recovery
   - Impact on the entire value chain
   - An IRR model (including cost recovery time frame).

2. **Sensitivity analysis**
   The commercial analysis should identify key variables that impact on the viability of internal scanning technology. These variables will include for example:
   - Log throughput volume and linear feed speed
   - Machine performance deliverables to achieve value outcomes related to IRR
   - Technology related costs (capital, integration, R&D, servicing, training, personnel)
   - Value (volume and grade) improvement
   - Effect on market pull through and product mix
   - IRR
3. **Commercial and technical risk**
The study must determine the commercial and technical risks associated with internal scanning. A thorough independent assessment should include:
- Identification of potential technology providers and the availability/cost of the technology
- Due diligence on selected technology providers
- Assessment of the local and global market for a viable technology

4.5.2 **Project timelines and cost**
The table below summarises an estimate of the duration and cost of the recommended commercial feasibility study.

<table>
<thead>
<tr>
<th>Milestones</th>
<th>Time</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formation of COI</td>
<td>3 months</td>
<td>In-kind</td>
</tr>
<tr>
<td>Engage Analyst (Tender)</td>
<td>2 months</td>
<td>In-kind</td>
</tr>
<tr>
<td>Project Interim reports monthly</td>
<td>4 months</td>
<td>$120,000 + In-kind</td>
</tr>
<tr>
<td>Report &amp; dissemination</td>
<td>2 months</td>
<td>In-kind</td>
</tr>
</tbody>
</table>

4.6 **Conclusion**
The viability of CT log scanning or internal scanning in general is essentially in the hands of the forest products industry and the relevant technology providers. A case for internal scanning exists when key internal quality and value information cannot be inferred externally as has been demonstrated in this project for resin defects in slash pine. Whether the internal information is pursued using sophisticated technology, which it must be, will depend on the results of a detailed financial assessment. CT companies manufacture a narrow product line or they construct one-off systems for a wide range of clients. To interest a manufacturer in the development of a log scanner will require a compelling business case to divert attention from core business and will certainly involve a significant investment from the timber industry partner/s. A credible business case would necessarily require the identification of a potentially large application market and a selection of one or a small number of most likely CT technology providers.

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