RD&E Program in Advanced Log and Woodchip Export Supply Chain Management for Australia

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RD&E Program in Advanced Log and Woodchip Export Supply Chain Management for Australia

Final Report Prepared for

Forest & Wood Products Australia

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R/D&E Program final report summary

Extensive industry consultation was held within the first months of starting period of this R/D program. Several forest companies (including HVP, FCNSW, Forico, HQP, Forestry SA, WAPRES, Bunbury Fibre, Midway, GTFP, STT, PF-Olsen and ISO Marshalling Pty Ltd) were selected as industry steering committee members. The industry committee reviewed the planned research activities and selected the most important and relevant ones to be fit with their R/D requirements. These included value and quality assessment, measurement/inventory assessment, phytosanitary test and wood loading technologies. HQP, FCNSW and Forico hosted various field trials on log loading and wood measurement. Summary of research findings of conducted trials has been classified in four components and presented as following;

1- Value and quality assessment

1-1- Technology review on log level chain of custody track and trace system:

A technical review of tag, track and trace systems was undertaken from the perspective of the Australian forest industries. Log tagging has enormous potential for improving production efficiencies in the log supply chain from stump to mill or port and ensuring that the right kind of timber is used for the end product that it is best suited for. Tag, track and trace systems at the individual log level are well established from the port gate in Australasia to international customers. A range of technologies, from branding hammers to DNA coding are potentially suitable for use in Australia. Three tagging technologies would appear to be most suitable for application on a harvester head in the near future. These are ink-jet printing of matrix codes, RFID tags, and punch code tags. Further development of these technologies on a harvester head is required. Machinery manufactures have been slow to undertake this development perhaps because the actors in the forest-to-customer supply chain have been slow in asking for it. The tag is only one part of a tag, track and trace system. The full benefits of tag, track and trace systems will undoubtedly require merging of forest to port gate (or mill) track and trace systems with the established systems from the port gate to the international customer. Improved communication between on-forest harvesting operations and on-wharf operations will be essential if this is to happen.

1-2- Log-end near infrared spectroscopy for moisture content measurement

The moisture content of fresh logs can account for 50% or more of the mass of a log. Transport of logs from forest to mill therefore involves cartage of unwanted water that contributes to the cost of cartage, which is weight-based. Storage of logs in-forest prior to transport can reduce the moisture content of logs. It is desirable therefore to be able to determine the moisture content of logs to determine suitable timing of transport. Near infrared (NIR) spectroscopy has been used successfully in the agricultural sector to determine moisture content in crops. It has been used in this study to measure the moisture content of discs from three species (*Araucaria cunninghamii* (Hoop pine), *Pinus radiata* (radiata pine) and a hybrid pine (*P. elliottii* x *P. caribea*)). Two separate NIR instruments were used: a portable instrument that is used in contact mode at a point on the disc (heartwood and sapwood were measured) and an industrialised system that acquires spectra from a distance of ca. 0.3-0.5 m to provide a single spectrum that is the average of the whole disc. The discs, representing a log end, were weighed, scanned by NIR and successively dried in a forced-air oven, re-weighed and re-scanned at each step to produce a series of matched spectra and gravimetric moisture content of the whole disc. Partial least squares regression was used to develop calibration models of NIR spectra with respect to whole-disc moisture content.

2- Measurement/inventory assessment

2-1- Sensor technologies for volumetric measurements of logs on trucks

Since wood represents an important proportion of the stump-to-mill delivered costs, it is important to adopt and implement correct measurement procedures and technologies that provide better wood volume estimates of logs on trucks. Poor measurements not only impact the revenue obtained by haulage contractors and forest companies but also might affect their contractual business relationship. The advantages of solid volume as a unit of measuring and payment for wood and chips have recently recognised by an increasing number of forest companies worldwide, many of which have commenced to embrace commercial mechanisms and implement rate systems based on volumetric measurements. At least three technologies (laser scanning, stereoscopic cameras, and photogrammetry and 3D reconstruction) have evolved and improved substantially over the last decade, providing quicker and more accurate measurements of standing trees, logs, and woodchips. The implementation of these technologies in real life operations requires that commercial mechanisms are adopted and implemented. This must also take into consideration the legal and commercial terms associated with implementing new measurement systems for payment on a volumetric basis, as well as the capital and running costs of the technology to be implemented. This is true for laser scanning, which despite being a mature and more affordable technology in the forestry domain, it remains expensive to adopt and implement in operating conditions.

This report provides an extensive literature review of laser, stereoscopic and photogrammetric systems for truckload volumetric measurements. It also reports the results of study on the use of multi-view structure from motion (SfM) photogrammetry and commercial 3D image processing software that were tested as an innovative and alternative method for automated volumetric measurement of truckloads. The images were collected with a small UAV, which was flown around logging trucks transporting Eucalyptus nitens pulplogs. Photogrammetric commercial software was used to process the images and generate 3D models of each truckload. The levels of accuracy obtained with multi-view SfM photogrammetry and 3D reconstruction obtained in this study were comparable to those reported in previous studies with laser scanning systems for truckloads with similar logs and species. The deviations between actual and predicted solid volume of logs on trucks ranged between -3.2% and 3.5%, with an average deviation -0.05%. In absolute terms, the average deviation was only 0.5 m^3 or 1.7%.

2-2- Automated detection and diameter estimation of stacked logs: A review and preliminary study

Measurement of logs stacked at the roadside or on trucks is time-consuming and labour expensive. Manually measuring logs can be inaccurate, not consistent among people (scalers), therefore, prone to errors. Poor measurements not only impact the revenue obtained by haulage contractors and forest companies but also might affect their contractual business relationship.

In the last years, several commercial mobile applications have been developed, which have enabled to measure stacked logs, logs in containers, on trucks, etc, in a much easier and effective way than traditional methods. While these apps have helped resolve the above issues, just a few studies have been conducted to confirm the levels of accuracy these commercial companies claim and report.

A preliminary study was conducted to determine the accuracy of automated, computer-vision measurements of logs on trucks, and compare these estimates with actual manual measurement methods. Diameter estimates from computer vision algorithms were compared with manual diameter measurements, and the measurement errors calculated. For this purpose, digital images of end faces from logs carried on one-trailer trucks were collected in 2018 at the weighbridge of a sawmill owned by a Chilean forest company. All the images in this study were in RGB colour format, and the size of each image was 640 x 480 pixels. In total, the data consisted of 22 digital images (11 truckloads) acquired with the same camera and containing a total of 215 Radiata pine debarked sawlogs. Each load was photographed from both sides to capture the small end diameters (SED) on each side of the load, and a computer vision-based novel approach was developed for the detection and estimation of diameters of logs on trucks. The image processing and detection algorithms were implemented in a tool named LogVision, based on OpenCV algorithms and developed with the Qt/C++ framework.

The results obtained in this study were promising. They showed that the difference between the diameters calculated manually and with LogVision was on average -0.13 cm, with a maximum of 6.7 cm and a minimum of -5.9 cm, with positive and negative errors seem to be well distributed across the SED range. In percentage terms, the mean error for the 215 logs analysed was only -0.6%, varying from -0.2% (SED class 32-34 cm) to -3.4% (SED class 30-32). The solution method presented has the potential to detect and estimate diameters of logs on trucks quickly and with a relatively high accuracy, which makes it suitable for use in operational conditions. Further studies will test an improved algorithm in different conditions in Australia (species, log size, luminosity etc.), compare different image capturing and pre-processing techniques, provide volumetric estimates based on a combination of photogrammetric (3D reconstruction) and computing vision algorithms, and also quantify the economic impact that results from using these technologies.

3- Phytosanitary test

3-1-Brief #1: Chemical treatments for wood exports and biosecurity trends

This brief provides a synopsis of ongoing research and activities pertaining to wood export phytosanitary considerations, chemicals, best practices and emerging trends. In this edition is ongoing research surrounding Methyl Bromide and chemical fumigants, Biosecurity Innovations (UAV Cyborg pest detection and mobile Apps) and a summary of phytosanitary log exports to China from Australia.

3-2-Brief #2: Export implications of sapstain, debarking and moisture content

This brief highlights ongoing work surrounding a recent FWPA project involving the broader wood export supply chain directed at evaluating sapstain, debarking, moisture content and the associated value impacts to regional export markets. Some highlights and considerations for bulk and containerised shipping are also discussed.

3-3-Debarking and drying effects on log weights and implications for exporting logs in containers

Internationally most logs are exported in bulk, or loose, form. A small proportion is exported in containers. The opportunity to backload logs, in what would have been empty containers otherwise, is attractive to some shipping companies and competitive shipping prices can be offered. Containers loaded with logs often reach their weight limit before they reach the space capacity in the container.

Three sets of trials were established in Queensland (utilising native hoop pine and F2 hybrid pine logs) and Western Australia (utilising radiata pine logs). Six treatments, based on three storage conditions (inside container, outside container in shade, and outside container in sun) and two bark states (debarked and non-debarked), were included in the trials. Trials lasted up to 96 days post-harvest and were repeated for four seasons. Models were developed for changes in bark weight and moisture content. There were significant differences between species in bark weight, expressed as a percentage of total log weight; i.e., 5.6, 10.4, and 16.0% for radiata pine, F2 hybrid pine, and hoop pine respectively

If the logs are not debarked Japanese Agricultural Standard (JAS) volume capacity per container may increase by up to 6.5% after 40 days of drying and will be dependent on log size. The larger the log size the smaller the gains from drying. Significant gains in JAS container volume are likely to occur, however, when the logs are debarked (3 to 14% depending on species, log size and season) and dried; e.g. up to 24% for hoop in summer and winter dried for 40 days. Even with higher JAS volumes per container, maximum container weight would remain the limiting factor, not space within the container.

Load rates were estimated to be up to eight times faster for logs in containers that had been debarked and dried (>1000 JAS m^3 per crane per hour) versus for bulk cargo log loading (140 JAS m^3 per crane per hour).

3-4-An Analysis of the economics of debarking, drying and anti-sapstain treatment in conifer log export supply chains

Bark has relatively little economic value in most tree species, hence most wood processors buy logs in terms of their wood fibre beneath the bark and specify diameter limits in terms of under bark measurements. In most forest-to- mill supply chains bark is removed prior to processing logs into wood products. Debarking and drying of logs also provides an opportunity for improving the economics of log handling (via weight reduction) and potentially reducing the requirement for phytosanitary fumigation treatments in export supply chains. Debarking and air drying of logs, however, alters the log's exposure to sapstain risk and may result in a value degrade over extended periods of logs are not anti-sapstain treated. In the forest-to-shipside portion of the export supply chain logs can be not debarked or they can be debarked in-forest, at a satellite yard, or at port. Logs can be not dried or dried in-forest or at a satellite yard. Logs can be left untreated or can be anti-sapstain treated at a satellite yard or at port.

A model was constructed that allowed the economic evaluation of alternative debarking locations, drying locations and anti-sapstain treatment locations. Data, gathered as part of the FWPA-funded export supply chain project, on log drying rates, bark weights, sapstain incidence, and log price reductions due to sapstain were utilised in the model construction. The impacts of debarking, drying for up to 30 days, and anti-sapstain treatment on harvesting costs, cartage costs, satellite yard costs, port costs, forest re-establishment costs, log prices and revenues were included in the model. Thirteen combinations of debarking location, anti-sapstain treatment and drying were evaluated for three conifer species (radiata pine, F2 hybrid pine, and Hoop pine) and two seasons (Winter and Spring) – giving a total of 78 treatment scenarios. Net revenues were ranked from highest to lowest for each of the three species for each of the two seasons. The scenarios with the highest net revenues differed by species and season.

In-forest debarking, along with no anti-sapstain treatment would be expected to give the highest net returns during winter operations for all three species. For two of the species (radiata pine and Hoop pine) in-forest drying also would be expected to give the highest net returns. For the F2 hybrid pine, better returns would be expected with no log drying. For spring operations, debarking at the port, along with no anti-sapstain treatment would be expected to give the highest net returns for radiata pine and F2 hybrid pine. In-forest debarking and drying, with no anti-sapstain treatment would be expected to give the highest net returns for Hoop pine. The relative differences in net revenue caused by debarking, drying, anti-sapstain treatment and location are covered in some detail in the report.

4- Wood loading technologies

4-1-Productivity and costs of containerised log loading

Repositioning empty containers from container surplus to container deficit regions around the world is a large operational cost for shipping companies. The opportunity to backload logs, in what would have been empty containers otherwise, is attractive to some shipping companies and competitive shipping prices can be offered. This report provides an international review of container handling and loading systems in log yards and presents case studies of container log loading systems that are currently operational on the east coast of Australia. The case studies relate to softwood log exports from plantation forests. A web-based review indicated that there is a wide range of systems being used for loading logs into containers. These range from simple, low capital cost, labour intensive systems to higher capital cost, purpose-built loading machines. The movement of empty and loaded containers around the log yard, along with storage areas for the containers, is a significant time and cost element. The three case studies and two additional simulated systems included in the analyses indicated that productivity (range = 3.8 to 7.7 containers per hour) and unit costs (range = \$4 to \$10 per JAS m^3 [excluding unloading of logs from trucks and scaling costs) can be expected to vary due to, among other things, differences in system configurations, lengths of logs being handled, target container weight limits, and species. Damage to containers was cited by log yard owners as being a potential issue for some loading systems. The costs of container damage were not studied or included in this report.

4-2-Loading rates and compaction factors for woodchip vessels visiting Australian ports

Loading rates and compaction factors (a relative measure of the amount of material loaded) were quantified via surveys for Australian woodchip exporting ports. Opportunities were identified for increasing loading rates and compaction factors through interviews with woodchip exporting companies, analysis of detailed ship loading data, and literature reviews.

Maximum potential load rates at Australian ports ranged from 670 to 1200 green metric tons per hour. Net loading rates were on average 30% slower than the maximum potential loading rates. Factors found to affect loading rates included: the type of shore-to-ship delivery system (e.g., mobile vs fixed conveyors, multi-product delivery vs woodchip only design), the tree species being loaded, conveyor rates, use of deflector plates on jet slingers, use of dozers in the hold for chip re-distribution and compaction, and layering of the chips. Compaction factors at Australian ports ranged from 137 to 170 ft^3 per bone dry metric ton. A literature review identified that compaction factors can be affected by pre-treatment of logs prior to chipping (e.g. in-forest drying), the type of system used to deliver chips to the vessel, vibration of the load post-loading, redistribution of the chips during loading, and compression of the load during loading. Analysis of data provided by one Australian woodchip exporting company showed that compaction factors were affected by the tree species being loaded (with higher density species having lower compaction factors), the order in which holds were loaded, the conveyor rate, use of deflector plates on jet slingers, use of dozers in the hold, and the layering system used. Compaction factors were not affected by jet slinger speed. Other companies commented that compaction factors were affected by the type of material being harvested (plantation vs native, conifer vs hardwood), the loading pattern (e.g. 80% fill followed by 20% top-off), the loading method and equipment (e.g. machine for redistributing and compacting chips in the hold vs jet slinger vs jet slinger with deflector plate), the skill of the loader operator, the wood chip specifications, and the moisture content of the woodchips.

Each 1% improvement in compaction factor is worth $35,000 to $60,000 in additional income per vessel for the exporter. Maximising net returns can result in a trade-off between loading rates and compaction factors. This study provides information that should help decision makers to select the work methods and equipment which will lead to the greatest net returns for the exporter.

4-3-Bulk material loading and operational technology trends

A brief technology review was carried out on the use of robotics, sensor systems, and automation for increasing bulk handling ship loading rates in non-forest industry products (e.g. grain, coal, iron ore). Forest products including Australian woodchip, logs and pellets are considered minor bulk exports by the industry compared to higher global tonnage exports including iron ore, coal and bulk grains. This review explores technology highlights from other sectors including handling systems (conveyors, feeders), loader designs, sensor applications (LiDAR systems, software suites, etc.), and autonomous concepts (terminals, loaders, ships) currently being employed or developed to help shape next generation bulk export supply chains.

Workshops: The forest industry partners of this R/D& E program were engaged to properly discuss the research results and outcomes. A workshop was held in SE QLD at HQP's Beerburum office in 18/07/2019. Based on industry demand 6 webinars were delivered during October and November 2019. Workshop and webinars were successfully delivered which enabled researchers receiving productive feedback and useful suggestions from industry representatives. Industry representative were provided with short and effective brief on trials conducted and results found within this R/D&E program.

Conclusions and recommendations

This R/D&E program comprehensively investigated the various aspects of Australian log and woodchip export supply chain management to achieve its main objective on identifying and implementing innovative technology, methods and best practices for efficient and effective timber export. The early trials within this program indicated that tag, track and trace systems are essential parts of the business in many industries. The benefits for the forestry sector are many and include curbing illegal logging and wood theft, providing a chain-of-custody proof for environmentally certified products, improved logistics and stock control management, improved ability to identify, allocate, and track logs from stands or trees with wood properties, and facilitating comparisons between forecast and achieved yields. Tag, track and trace systems at the individual log level are well established from the port gate in Australasia to international customers. Little use of these systems currently occurs between the forest and the port gate, however. Three tagging technologies would appear to be most suitable for application on a harvester head in the near future. These are ink-jet printing of matrix codes, RFID tags, and punch code tags. Further development of these technologies on a harvester head is required, however. Machinery manufactures have been slow to undertake this development and implement these technologies on harvester heads, perhaps because the actors in the forest-to-customer supply chain have been slow in asking for it. Forest owners, harvesters and log exporters should communicate their need for the development of at least one of these technologies to machinery suppliers and manufacturers. Near infrared spectroscopy trial results (in HQ Plantations in SE Queensland) indicated that this technique can be also used in either contact mode or stand-off mode to provide a rapid assessment of a cross-sectional wood disc and by extension this should be possible to perform on a log-end.

Different sensor technologies for volumetric measurements reviewed within this R/D&E program, laser scanning is perhaps the most mature and proved technology, and potentially suitable for Australia. Just recently, Forico Pty Limited has implemented the Logmeter laser scanning systems at the Surry Hills chipmill in Northern Tasmania, being the first unit of this type operating in Australasia. Application of computer vision technologies tested in this research program is a novel approach for detection and estimation of diameters of logs on trucks. This has the potential to detect and estimate diameters of logs on trucks quickly and with a relatively high accuracy, which makes it suitable for use in operational conditions. Further studies will test an improved algorithm in different conditions, compare different image capturing and pre-processing techniques, provide volumetric estimates based on a combination of photogrammetric (3D reconstruction) and computing vision algorithms, and quantify the economic impact that results from using these technologies. Application of volumetric measurement and computer vision technologies would require training programs for the industry users to facilitate translating the research findings into practices.

Debarking and drying of logs were studied in South East Queensland (in collaboration with HQ Plantations) and South West Western Australia (in collaboration with Forest Products Commission, Total Harvesting, Inglewood Forest Group, and Australian Bluegum Plantations). The results indicated that debarking and drying can affect log quality attributes, such as sapstain incidence and severity, wood permeability, and log-end checking. Sapstain incidence and severity increased with time. The time required to reach severity levels that would negatively impact log prices, however, differed between species (with *Araucaria* being less affected than the *Pinus* species) and season of the year (with Autumn being less affected and Spring being most affected across all species). Sapstain severity could generally be reduced by either not debarking the logs or by storing them in a container. Storage of Hoop pine in a container in the summer season, however, resulted in high sapstain severity levels. Log-end checking also increased with time and was lower with Hoop pine than F2 hybrid pine. It could also be reduced by not debarking the logs. Debarking and drying of logs can also affect the incidence of insects and phytosanitary requirements. Insect incidence increased with time, temperature and humidity. It differed between species, with incidence tending to be lower in Hoop pine than in F2 hybrid pine. Insect incidence could be reduced by debarking logs and storing them in containers.

From economic perspective debarking and drying of logs also provides an opportunity for reducing the cost of log handling (via weight reduction) and potentially reducing the requirement for phytosanitary fumigation treatments in export supply chains. Debarking and air drying of logs, however, alters the log’s exposure to sapstain risk and may result in a value degrade over extended periods if logs are not anti-sapstain treated. An economic model was developed in this project that allowed the economic evaluation of alternative debarking locations, drying locations and anti-sapstain treatment locations. Compared with doing nothing, i.e., not debarking, not drying, and not anti-sapstain treating logs, study results indicated that there were at least three treatment combinations, that differed between seasons and between species, which could be expected to yield improvements in net returns. On the other hand, half of the treatment combinations could be expected to result in lower net returns than doing nothing. Note that doing nothing means that logs are still fumigated. The optimum treatment combinations were not consistent across all seasons and all species evaluated. Given that treatments, other than drying, are not likely to change between seasons, but could differ for different species, preferred treatment combinations might be as follows:

- Radiata pine – either debark at the port, do not anti-sapstain treat, and do not dry; OR debark in-forest, do not anti-sapstain treat, dry in winter but do not dry in spring
- F2 Hybrid pine – debark in-forest, do not anti-sapstain treat, do not dry
- Hoop pine – debark in-forest, do not anti-sapstain treat, dry

Studies conducted on wood loading technologies within this RD&E program provided useful information on improving work efficiency. Hummels (2007) commented that containerships are much quicker for loading and unloading than with bulk cargo. This comment is supported by study results of our research which showed that average load rates for logs in containers were up to six times faster than those for bulk cargo logs. With debarking and partial drying of logs load rates could be as much as 10 times faster. Faster load rates should mean shorter voyages, lower port costs and reduced likelihood of demurrage fees. So why aren't more logs exported in containers? Loading logs into containers before they are loaded onto ship is an additional step in the forest to customer supply chain and requires time, space and cost. Repositioning empty containers from container surplus to container deficit regions around the world is a large operational cost for shipping companies. The opportunity to backload logs, in what would have been empty containers otherwise, is attractive to some shipping companies and competitive shipping prices can be offered. A web-based review indicated that there is a wide range of systems being used for loading logs into containers. These range from simple, low capital cost, labour intensive systems to higher capital cost, purpose-built loading machines. The three case studies and two additional systems included in the analyses indicated that productivity and unit costs can be expected to vary due to, among other things, differences in system configurations, lengths of logs being handled, species and onward transport systems. Interviews and historical data showed that there is substantial variability in loading rates and compaction factors between ports. The key factors affecting these were also identified. Each 1% improvement in compaction factor is worth $35,000 to $55,000 in additional income per vessel. Maximising net returns can result in a trade-off between loading rates and compaction factors. Study results confirmed that loading rates and compaction factors are affected by many variables, including tree species, conveyor rates, in-hold chip redistribution equipment, the loading pattern, operator skills, shore-to-ship delivery systems, etc.

To remain competitive in a global environment, whole of system wood export supply chains must continue to innovate, adapt and adopt emerging technologies. The integration of downstream supply chain activities (felling, transportation, tracking, etc.) to efficient export operations will continue to be important. Port operations including loading, handling and shipping considerations are all core elements to a company's export costs and financial viability. Various aspects of technological innovation were reviewed by the research team. The aspects varied from handling systems (chutes design to more effectively load and compact material, eliminate dust, etc.) to advanced sensors used to automate the loading process, avoid costly collisions and delays, to supporting software packages, to more flexible loading systems and fully autonomous technology integrated into the worlds most advanced terminals and proposed vessels. Trends clearly indicate the world's most progressive supply chains are innovating old technology (chutes, loaders), adapting mobile and flexible systems and embracing autonomous equipment and methods to lower labour costs, improve efficiency, handling density and port safety. Macro trends, including the construction and retrofitting of ports to employ terminal scale automated technology, will continue to put downward pressure on acceptable export costs. This long-term outlook highlights the need for the forest industry to collaborate, co-invest and continue to work with port operators to ensure lowest cost operations to maintain competitive.

Note: 1) The full text of all technical reports is provided as appendix to this document. 2) A list of workshops and webinars including a short description of each workshop/webinar is also attached.

Debarking and Drying Effects on Log Weights and Implications for Exporting Logs in Containers

Prepared for

Forest & Wood Products Australia

by

Glen Murphy, Helen Nahrung, Michael Ramsden, Rick Mitchell, and Michael Berry

Executive summary

Internationally most logs are exported in bulk, or loose, form. A small proportion is exported in containers. The opportunity to backload logs, in what would have been empty containers otherwise, is attractive to some shipping companies and competitive shipping prices can be offered. Containers loaded with logs often reach their weight limit before they reach the space capacity in the container.

Three sets of trials were established in Queensland (utilising native hoop pine and F2 hybrid pine logs) and Western Australia (utilising radiata pine logs). Six treatments, based on three storage conditions (inside container, outside container in shade, and outside container in sun) and two bark states (debarked and non-debarked), were included in the trials. Trials lasted up to 96 days post-harvest and were repeated for four seasons. Models were developed for changes in bark weight and moisture content.

There were significant differences between species in bark weight, expressed as a percentage of total log weight; i.e., 5.6, 10.4, and 16.0% for radiata pine, F2 hybrid pine, and hoop pine respectively

If the logs are not debarked Japanese Agricultural Standard (JAS) volume capacity per container may increase by up to 6.5% after 40 days of drying and will be dependent on log size. The larger the log size the smaller the gains from drying.

Significant gains in JAS container volume are likely to occur, however, when the logs are debarked (3 to 14% depending on species, log size and season) and dried; e.g. up to 24% for hoop in summer and winter dried for 40 days. Even with higher JAS volumes per container, maximum container weight would remain the limiting factor, not space within the container.

Load rates were estimated to be up to eight times faster for logs in containers that had been debarked and dried (>1000 JAS m^3 per crane per hour) versus for bulk cargo log loading (140 JAS m^3 per crane per hour).

The economic benefits of debarking and drying practices are likely to be dependent on the incidence and severity of sapstain, insect infestation and log checking. The results of sapstain and insect research undertaken along with the debarking and drying trials will be given in a separate report.

Table of Contents

Executive Summary i
Introduction 1
Factors Affecting Log Drying 2
Study Methods 3
Results 7
  Change in Log Weight with Bark Removal 7
  Change in Log Weight with Drying 8
  Combined Effects of Debarking and Drying 10
Implications for Exporting of Logs in Containers 11
References 13
Appendix. Graphs depicting drying of F2 hybrid and hoop pine logs in Queensland 13

Introduction

In 2016 Australia was the world's sixth largest exporter of logs, accounting for about 3% of total exported roundwood in that year (3.9 million m^3 of the 132 million m^3 exported) (FAO 2017). Most logs from Australia are exported in bulk, or loose, form. However, there is small proportion exported in containers, mainly to Asia. Other parts of the world are also exporting logs in containers, including Africa, Europe, Canada, USA, and New Zealand.

Why ship logs in containers? Regional trade imbalances mean that many shipping companies are faced with repositioning empty containers from container surplus to container shortage locations. Repositioning empty containers can be a significant operational cost (Epstein et al. 2012). The opportunity to backload logs, in what would have been empty containers otherwise, is attractive to some shipping companies and competitive shipping prices can be offered. The other big benefit for both exporters and importers is that small lots of just a few hundred cubic meters can be delivered and the exporter isn't restricted to the main ports that can handle bulk logs. This opens up the market to niche buyers and sellers serviced by more ports (Weblin 2008). Gains in forest gate returns of up to \$10 per JAS m^3 have been reported.

Loading logs into containers, and unloading them again on arrival at their destination, requires some effort and cost (Murphy et al. 2018). Hummels (2007) commented, however, that containerships are much quicker for loading and unloading than ships with bulk cargo. This comment is supported by analyses by Murphy (2018) which showed that average load rates for logs in containers were up to six times faster than those for bulk cargo logs.

Containers with logs in them are frequently loaded onto ships partially full as they reach their weight limit before they reach their volume limit (Figures 1 and 2). Weight limits for 40 ft dry cargo containers are set by an international shipping convention (SOLAS)[1] at 27,600 kg or less depending on the road or rail transport regulations of the exporter's or importer's country.

Figure 1. Huangdao Container Terminal in China showing containers that are ¾ "full" due to 25 metric ton weight restrictions. (Source: tptforests.com)

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[1] http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx (accessed 16 August 2018)

Figure 2. The two containers on the left and right of the photo are "full", having reached their maximum allowable weight limit. The photo was taken in a log yard in Queensland.

Debarking and partial drying of logs before loading them into containers should result in an increase in the average solid wood content per container. This process, however, could affect the incidence and severity of sapstain, and infestation by insects occurring within exported softwood logs.

This publication is the first of three which report the results from debarking, drying and sapstain trials undertaken in Queensland and Western Australia in 2018-19. It will focus on the effects of debarking and drying on log weights. The other two will report on the economic viability of debarking and drying practices in relation to sapstain development, insect infestation and log checking.

Factors Affecting Log Drying

Wood is about 50% water by weight. International studies have shown that infield drying of logs can result in reductions in their wet basis moisture content[2] (MC) of 20% or more (Kent et al. 2010, Roser et al. 2011, Murphy et al. 2012, Visser et al. 2014, Strandgard and Mitchell 2017).

Wood will seek an equilibrium moisture content in relation to the relative humidity of its surroundings. For wood to dry, the moisture content of the air must be less than that of the wood (Reeb 1997). Because wood is a hygroscopic material, it can also take up and retain moisture if the moisture content of the air is greater than that of the wood. The main driving force of water transport in wood is capillary diffusion. Water can diffuse at a rate up to 15 times higher in the longitudinal direction (along length of the log) than in the radial direction (from the centre to the edge of the log) (Reeb 1997).

In addition to weather conditions (Stokes et al. 1987, Erber et al. 2014, Strandgard and Mitchell 2017), tree species (Simpson and Wang 2004, Kim and Murphy 2013), log size (Stokes et al. 1987, Kim and Murphy 2013, Visser et al. 2014), presence or absence of bark

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[2] Moisture content of wood expressed as a percentage of the green weight of wood including moisture.

(Rosser et al. 2011, Bown and Laserre 2015), and covering of logs to protect them from rewetting (Roser et al. 2011, Murphy et al. 2012) have been shown to affect drying rates and the number of storage days to reach a given moisture content.

A number of variables have been used by researchers in air-drying models to represent weather conditions. These include:

- Relative humidity (Simpson and Wang 2004, Bown and Laserre 2015, Strandgard and Mitchell 2017)
- Temperature (Stokes et al. 1987, Simpson and Wang 2004, Erber et al. 2014)
- Wind (Murphy et al. 2012)
- Solar radiation (Murphy et al. 2012)
- Precipitation (Stokes et al. 1987, Liang et al. 1996, Murphy et al. 2012)

Study Methods

Debarking, drying and sapstain trials were carried out for four seasons beginning in Autumn 2018. As noted earlier a description on the sapstain portion of the trials will be presented in a separate report.

Study Locations

Replicated trials were carried out at three locations; one in Western Australia and two in Queensland.

The Western Australian trials were located at the port of Albany (Lat. -35.036, Long. 117.903, Elevation 3 m). Radiata pine (*Pinus radiata*) logs were used in these trials. The first trial began in mid-June 2018 (Winter), and was repeated in Spring and Summer seasons, ending in early-March 2019.

Two softwood taxa were used in the trials in Queensland: hoop pine (*Araucaria cunninghamii*) and F2 hybrid pine (*Pinus elliottii X Pinus caribaea*). The hoop pine field trials were located at two sites near Yarraman (Lat. -26.841, Long. 151.981, Elevation 407 m), within Googa and Yarraman State Forests. The F2 pine trials, as well as the hoop pine container trial, were located within Beerburrum State Forest (Lat. -26.955, Long. 152.962, Elevation 45 m). The first hoop pine and F2 pine trials began in late-April 2018 (Autumn) and were repeated in Winter, Spring and Summer seasons, ending in mid-March 2019.

Treatments

Sufficient logs were provided by the forest companies involved in the trials so that three piles of approximately 8 tonnes each could be formed (Figures 3, 4 and 5). Logs were 3.8 m in length and were positioned on two runner logs so that the bottom logs were not in contact with the soil.

In the Western Australian trial one pile of logs was stored in a 20 ft (~ 6m) container (CONTAINER), one pile was stored outside a container in shade (SHADE), and one pile was stored outside a container without shade (SUN). The Queensland trials varied slightly due to the use of two softwood species which are grown in separate geographical locations. Hoop pine SHADE and SUN log piles were therefore situated inland (higher mountainous elevation) within the State Forests where they were harvested. The containerised hoop trial component was undertaken at Beerburrum (lower coastal elevation), as were the containerised F2 hybrid and its SHADE and SUN piles.

Approximately half of the logs in each pile were debarked (BARK OFF), and half were not (BARK ON). BARK OFF and BARK ON logs were mixed within each pile and container.

These six treatments (CONTAINER BARK OFF, CONTAINER BARK ON, SHADE BARK OFF, SHADE BARK ON, SUN BARK OFF, SUN BARK ON) were repeated at each of the three locations for each of the four seasons (three seasons only in WA).

Western Australian trials ran for a minimum of 42 days and a maximum of 96 days, while in Queensland trials ran between 52 and 56 days (harvest to final measure).

Figure 3. Radiata pine debarked and non-debarked logs stored outside a container near Albany, Western Australia.

Figure 4. F2 hybrid pine debarked and non-debarked logs stored outside a container near Beerburrum, Queensland.

Figure 5. Preparing to collect wood disk from debarked and non-debarked hoop pine logs stored inside a container near Beerburrum, Queensland.

Data Collection and Calculations

Prior to sampling (cutting of wood disk), logs were assessed for surface mould, bluestain and insect infestation in the Queensland trials. Three wood disks (approximately 2.5 cm thick) were collected in the field for each of the six treatments at Day 0, and then at approximately 14-day intervals, thereafter. Each disk was cut from a different log approximately 10 cm from the log's end. Each disk was numbered (Figure 6) and placed in uniquely labelled plastic bags to maintain moisture contents. In the Queensland trials, logs were also assessed for surface mould, bluestain and insect infestation prior to sampling (cutting of wood disk. Additionally, in Queensland logs were removed from the piles and containers to allow for safe sampling. Sampled logs were not replaced back, therefore log piles reduced in number (six), following each separate sampling.

Figure 6. Radiata pine disk, collected on 2 August 2018, and uniquely numbered (F=Forest Cover [referred to as SHADE in this report], D=Debarked, 1=Disk #1).

The percentage of the circumference where bark was present was estimated for BARK ON disks. The over-bark and under-bark weights of each disk were measured in a laboratory to nearest 0.1g (except when the mass of large hoop disks exceeded 5kg in which case they were weighed to the nearest 100g on a larger balance). Over-bark diameters (average of two perpendicular measurements) and under-bark diameters (average of two perpendicular measurements) of each disk were measured to the nearest 1 mm. The thickness of each disk (average of four measurements 90° apart) was measured with a vernier calliper to the nearest 0.1 mm. The volume of each disk was calculated assuming the disk was a cylinder. Disks were then placed in a drying oven set at 103 degrees C for 24-72 hours (until the weight remained unchanged). Disks were re-weighed after drying.

Daily Australian Bureau of Meteorology (BOM) data were obtained for the Yarraman (Kingaroy BOM data utilised), Beerburrum and Albany locations. These included average relative humidity (RH%), average temperature (Temp) and precipitation (Rain) data. Data loggers were also installed at the two Queensland locations to record temperatures in the CONTAINER, SHADE, and SUN and relative humidity in the CONTAINER.

All data, including the number of days since each trial began, were entered into an Excel spreadsheet. The following calculations were made for each disk.

$$\textit{Bark Weight (Over-bark) (\%)} = \frac{\textit{Green Weight (Bark On) – Green Weight (Bark Off)}}{\textit{Green Weight (Bark On)}} * 100$$

$$\textit{Bark Weight Adjusted (Over-bark) (\%)} = \textit{Bark Weight (Over-bark) (\%)} * 1/(\textit{Percentage Circumference})$$

$$\textit{Bark Volume (Over-bark) (\%)} = \frac{\textit{Diameter (Bark On)}^2 - \textit{Diameter (Bark Off)}^2}{\textit{Diameter (Bark On)}^2} * 100$$

$$\textit{Moisture Content Wet Basis (Bark Off)(\%)} = \frac{\textit{Green Weight (Bark Off) – Dry Weight (Bark Off)}}{\textit{Green Weight (Bark Off)}} * 100$$

Average values at Day X were calculated for Bark Weight Adjusted (BWA%), Bark Volume (BV%), Moisture Content (MC), Under-Bark Diameter Squared (cm^2) (DSq) based on the three disks for each treatment. Eighteen disks were available for calculating average starting moisture content at Day 0.

BOM data between disk collection days were averaged. The average daily change in MC ($MC\Delta_i$) was calculated as follows:

$$MC\Delta_i \textit{ at disk collection period } i = \quad (MC_i - MC_{i-1}) / (D_i - D_{i-1})$$

where i = 0, 1, 2, 3, 4, etc., MC_i = moisture content at disk collection period i, and D_i = number of days since initiation of the trial to disk collection period i. A negative change means the logs are losing moisture, a positive change means the logs are gaining moisture.

Model construction

Data were analysed using STATGRAPHICS Plus 5.1 software. Multiple regression analysis procedures with backward selection were used to build models for BWA% and $MC\Delta_i$. Variables with α values > 0.05 were excluded from the models. Variables considered in the models were binary variables for BARK (0 = bark off, 1 = bark on), storage in a CONTAINER (0 = outside container, 1 = inside container), outside container storage conditions OUTSIDE (0 = shade, 1 = sun), Araucaria (1 = hoop pine, 0 = otherwise), and Radiata (1 = radiata pine, 0 = otherwise) and continuous variables for DSq, RH%, Temp, Rain, and moisture content at the beginning of the period (MC_{i-1}). Both non-transformed and natural-log transformed versions of the continuous independent variables were evaluated for inclusion in the models. Interactions between binary variables and continuous independent variables were also included in the initial models. Final model selection was based on examining Root Mean Square Error, Mean Absolute Error, and R^2 statistics.

Results

Change in Log Weight with Bark Removal

Multiple regression analysis indicated that BWA% was related to species only (R^2 adj = 0.79, $F_{2,143}$ = 273.9). BWA% was 5.6 (SE 0.2), 10.4 (SE 0.0), and 16.0 (SE 0.3) for radiata pine[3], F2 pine and hoop pine respectively. BVol% was 7.7 (SE 0.3), 14.8 (SE 0.0), and 14.8 (SE 0.3) for these three.

The above weights would relate to the situation where all bark is present on the logs at the time of export. Murphy and Acuna (2016), however, have shown that bark is lost as logs are handled in the supply chain and that the amount of bark loss is dependent on the harvesting season. Trials carried out in Australia and New Zealand found that radiata pine bark loss was greatest in Spring, intermediate in Summer and Autumn, and lowest in Winter. Cut-to-length harvesting systems, the predominant systems used in softwood plantations in Australia, could be expected to result in the approximate loss of 45%, 35%, 35%, and 25% of radiata pine bark during Spring, Summer, Autumn, and Winter respectively. Measures of bark loss for hoop pine and F2 hybrid pine species are unavailable, however anecdotal evidence suggests that losses may be significantly lower (4 to 15%), particularly for hoop pine, than those for radiata pine. However, the Murphy and Acuna (2016) loss estimates have been assumed in the following analyses for hoop pine and F2 hybrid pine. Sensitivity to this assumption is examined later in this report.

Purposefully removing all bark could be expected to result in the changes in log weight shown in Table 1. Two sets of estimates for radiata pine are given; one based on the BWA% found in the trials reported herein, and one based on a higher average value of 7.5%.

Table 1. Changes in log weight (%) adjusted for seasonal handling loss due to the removal of all bark.

Species	Season			
	Spring	Summer	Autumn	Winter
Hoop pine	9.5	11.0	11.0	12.5
F2 hybrid pine	6.0	7.0	7.0	8.0
Radiata pine (trial results)	3.2	3.7	3.7	4.2
Radiata pine (assume 7.5% BWA%)	4.3	5.0	5.0	5.7

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[3] Note that the BWA% and BVol% values reported here for radiata pine are significantly lower than reported elsewhere for mature radiata pine; e.g. 7 to 8% for BWA% and 12 to 13% for BVol% (Murphy and Cown 2015). This may be because the radiata logs used in the trial were of small diameter and possibly came from upper portions of the tree stem.

Change in Log Weight with Drying

The MC of logs tended to change with time but rate and direction of change appeared to differ between treatments and seasons (Appendix 1).

Average daily change in moisture content ($MC\Delta_i$) was related to moisture content at the beginning of a period (MC_{i-1}), average relative humidity (RH%), log size (DSq), presence of bark, and whether the logs were inside or outside of the container (Table 2). Once log size was included in the model differences between species were not significantly different. There were interactions between some variables; MC_{i-1} and presence of bark, and MC_{i-1} and use of a container.

The following model was developed for $MC\Delta_i$ (R^2 adj = 0.29, $F_{7,263} = 16.8$, $P < 0.001$):

$$MC\Delta_i = 5.824*CONTAINER + 2.527*BARK + 0.161*\ln(DSq) + 0.498*\ln(RH\%) - 0.882*\ln(MC_{i-1}) - 1.426*CONTAINER*\ln(MC_{i-1}) - 0.606*BARK*\ln(MC_{i-1})$$

Initial moisture contents (MC_0) averaged 51.3% (SE 0.8), 49.2% (SE 0.6) and 51.2% (SE 0.5) for radiata, F2, and hoop pine respectively. There were small differences in MC_0 between seasons, but only at the hoop pine trial was there a statistically significant difference; 54.4% for Spring versus 49.6% for the other three seasons.

Mean under-bark diameters were 17.1 (SE 0.2), 25.9 (SE 0.2), and 35.3 (SE 0.2) cm for radiata, F2 and hoop pine respectively.

Weather conditions, based on BOM data, for the trial locations are summarised in Table 2. Average relative humidities inside the containers ranged from 93.8% to 99.7%. It should be stressed that RH% in the model is based on BOM data, not container data.

Table 2. Summary of weather conditions by season for the three trial locations (Source: Australian Bureau of Meteorology records)

Location	Season	Average RH (%)	Average Temperature (°C)	Average Daily Precipitation (mm)
Albany	Autumn	81	17.6	1.3
	Winter	83	13.1	4.3
	Spring	69	16.3	1.2
	Summer	71	19.0	0.4
Beerburrum	Autumn	68	17.9	1.4
	Winter	56	16.4	0.9
	Spring	56	23.3	1.8
	Summer	57	25.1	3.7
Kingaroy	Autumn	73	14.2	0.4
	Winter	60	12.8	0.4
	Spring	58	22.4	0.8
	Summer	53	25.1	2.6

The effect of drying on the change in MC of the logs can be seen in Table 3 for a range of relative humidities. The results are calculated cumulatively using the above model and are based on debarked logs, resting on runners, outside of a container. Note that, although results are summarised by species, the differences between columns are due to the different average log sizes used in the trials, rather than any characteristics of the species themselves.

Table 3. Change in MC with drying time for debarked logs stored outside of a container.

Relative humidity %	Days Drying	Change in moisture content % (absolute) Radiata	F2	Hoop
50	10	-5.4	-4.2	-3.3
	20	-9.9	-7.6	-6.0
	30	-13.5	-10.4	-8.2
	40	-16.3	-12.7	-10.0
60	10	-4.6	-3.4	-2.4
	20	-8.4	-6.1	-4.4
	30	-11.5	-8.4	-6.1
	40	-13.9	-10.2	-7.5
70	10	-3.9	-2.6	-1.7
	20	-7.1	-4.8	-3.2
	30	-9.7	-6.6	-4.3
	40	-11.8	-8.1	-5.3
80	10	-3.3	-2.0	-1.1
	20	-6.0	-3.7	-2.0
	30	-8.2	-5.1	-2.8
	40	-10.0	-6.3	-3.4

Drying of non-debarked logs stored outside of a container results in a slower drying rate than debarked logs. After 40 days of drying, MC for non-debarked logs was 4.3 to 6.5% higher depending on RH% and log size; the difference was smallest for large logs in high humidity locations and largest for small logs in low humidity locations.

Storage of debarked logs in a container resulted in a smaller change in MC compared with debarked logs stored outside of a container. For example, debarked F2 hybrid logs inside a container could be expected to lose 2.0% moisture compared with 8.4% for logs stored outside of a container where the RH% was 60 over a period of 30 days.

Non-debarked logs stored in a container lost less moisture, or even gained a small amount of moisture, compared with debarked logs stored in a container. For example, non-debarked F2 hybrid logs inside a container could be expected to gain 0.5% moisture compared with 1.9% moisture loss for logs debarked logs stored inside of a container where the outside RH% was 60 over a period of 30 days.

Strandgard and Mitchell (2017) measured the change in MC for non-debarked, radiata pine chip logs stored near Manjimup, WA. After 40 days there was about a 4.5% drop in MC when drying began in Winter. For the climatic conditions at Manjimup during their trial, our model would have predicted the drop to be about 2% higher; i.e., about 6.5%. The difference was much greater for the Summer trial at Manjimup where the drop in MC in the first 40 days was about 20% and our model predicted the drop would be about 9.3%. The large difference is possibly due to the average log size in the Summer Manjimup trial being outside of the bounds of our data collection and modelling. The graphs provided by Strandgard and Mitchell (2017) show a faster drying rate with small radiata pine residue logs than with chip logs.

Combined Effect of Debarking and Drying on Log Weights

Table 4 shows modelled effects of debarking and drying on changes in log weights for four seasons at the three trial locations. Average relative humidities for each season from BOM data are applied. Differences between columns are due to differences in both average logs size effecting moisture loss and differences in bark weight for the three species in the trials.

There is up to a 21% range in the modelled change in log weights dependent on species, log size, season, storage type and debarking practice. It should be stressed that these numbers are based on the assumed seasonal changes in bark weight shown in Table 1 and the average log sizes measured in the trials. Two examples are presented to demonstrate the sensitivity of the modelled numbers to these assumptions.

In the first example, a 1.2% greater change in log weights would be calculated for radiata pine debarked logs stored outside a container for 30 days in summer (-14.1% vs -12.9%) if BWA% was 7 to 8% as reported by Murphy and Cown (2015) rather than the 5.6% found in our study.

In second example, a 2.7% greater change in log weights would be calculated for hoop pine debarked logs stored outside a container for 30 days in summer (-20.4% vs -17.7%) if log handling bark losses were 15% rather than the assumed 35% reported by Murphy et al. (2017) for radiata pine.

Table 4. Modelled effects of debarking and drying for 30 days on changes in log weights at three trial locations. Starting MC is assumed to be 50%.

Season	Treatment	Change in Log Weight % (absolute)		
		Radiata at Albany, WA	F2 at Beerburrum, QLD	Hoop QLD
Autumn	Outside, Bark On	-3.7	-2.7	-0.2
	Outside, Bark Off	-11.5	-13.5	-14.4
	In Container, Bark On	+0.7	+1.3	+3.0
	In Container, Bark Off	-5.4	-7.9	-9.9
Winter	Outside, Bark On	-3.5	-4.4	-1.9
	Outside, Bark Off	-11.7	-16.4	-17.8
	In Container, Bark On	+0.9	+0.0	+1.7
	In Container, Bark Off	-5.7	-10.3	-12.8
Spring	Outside, Bark On	-5.2	-4.5	-2.2
	Outside, Bark Off	-12.8	-14.6	-15.4
	In Container, Bark On	-0.4	+0.0	+1.6
	In Container, Bark Off	-6.1	-8.3	-10.0
Summer	Outside, Bark On	-4.9	-4.3	-3.0
	Outside, Bark Off	-12.9	-15.3	-17.7
	In Container, Bark On	-0.2	+0.2	+1.0
	In Container, Bark Off	-6.4	-9.2	-12.2

Implications for Exporting Logs in Containers

Murphy et al. (2018) reported average load volumes of 24.5 JAS m^3 and average weights of 26.67 tonnes for logs loaded into 40 ft containers at three Australian log yards. JAS volume conversion factors differ with log size and are based on under-bark diameter measurements. As shown in Figures 1 and 2 of this report, logs in containers often hit a weight limit before they are fully loaded volume-wise.

Table 5 shows the potential gains in JAS container volume that could be achieved for debarked and non-debarked logs that have been dried for zero up to 40 days outside of a container.

If the logs are not debarked the gains in JAS volume capacity are likely to be small, up to 6.5% after 40 days of drying, and will be dependent on log size. The larger the log size the smaller the gains from drying.

Significant gains in JAS container volume are likely to occur when the logs are debarked (3 to 14% depending on species, log size and season) and dried; e.g. up to 24% for hoop in summer and winter dried for 40 days. Even with higher JAS volumes per container, maximum container weight would remain the limiting factor, not space within the container.

Figure 6 depicts the impact of such gains on estimated ship loading rates for logs in containers versus loading of logs as bulk cargo. Murphy (2018) reported that load rates, on average, are about six times faster when logs are loaded in containers than when they are loaded as bulk cargo. Debarking and drying of logs prior to loading them into containers could result in load rates that are up to eight times faster than when logs are loaded as bulk cargo.

Table 5. Potential impact on JAS container volume (%) for various debarking and drying practices.

Species	Season	Debarked	Number of days drying outside of container			
			0	20	30	40
Radiata	Spring	No	0.0	4.2	5.5	6.5
	Summer		0.0	4.0	5.2	6.0
	Autumn		0.0	2.9	3.7	4.5
	Winter		0.0	2.7	3.5	4.2
F2	Spring		0.0	3.6	4.7	5.6
	Summer		0.0	3.4	4.5	5.3
	Autumn		0.0	2.0	2.8	3.2
	Winter		0.0	3.5	4.6	5.5
Hoop	Spring		0.0	1.7	2.4	2.8
	Summer		0.0	2.4	3.1	3.7
	Autumn		0.0	0.1	0.1	0.2
	Winter		0.0	1.4	1.9	2.2
Radiata	Spring	Yes	3.3	11.4	14.7	17.5
	Summer		3.8	11.6	14.8	17.5
	Autumn		3.8	10.4	13.0	15.2
	Winter		4.4	10.7	13.3	15.3
F2	Spring		6.4	14.0	17.1	19.8
	Summer		7.5	15.1	18.1	20.8
	Autumn		7.5	13.3	15.6	17.5
	Winter		8.7	16.6	19.6	22.4
Hoop	Spring		10.5	16.0	18.2	20.0
	Summer		12.4	18.9	21.5	23.8
	Autumn		12.4	15.6	16.8	17.9
	Winter		14.3	19.6	21.7	23.5

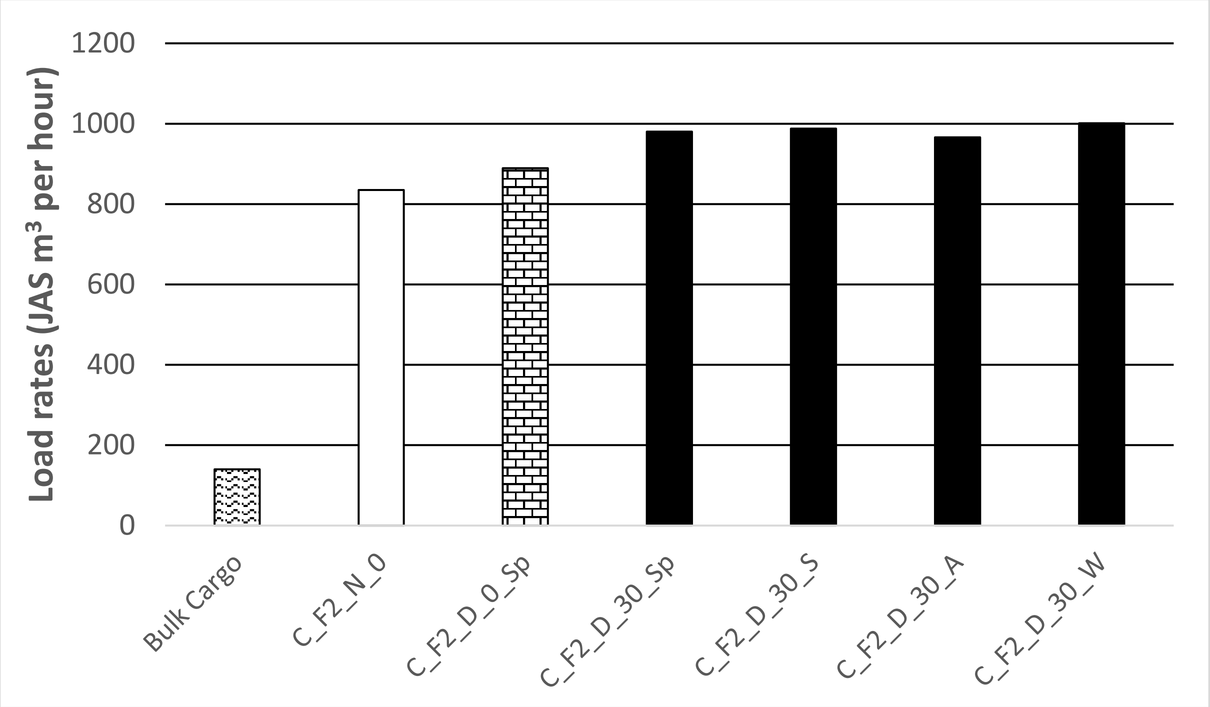

Figure 6. Estimated load rates for logs loaded in containers versus as bulk cargo. (Legend: Bulk Cargo = bulk cargo loading, C = container loading, F2 = F2 hybrid pine, N = Non-debarked, D = Debarked, 0 = 0 drying days, Sp = Spring, S = Summer, A = Autumn, W = Winter)

In this report we have examined the benefits of debarking and drying of logs on container load volumes and the implication for ship loading rates. The benefits are significant.

The model indicates that there may be some further drying of logs inside of the container but it is likely to be small, if not negative. Logs that had been first dried and then later stored in a container were not included in our set of trials. Further work should be carried out on this topic.

Murphy et al. (2017) reported that potential gains in net revenue of 3 to 9% were possible if logs were debarked in the forest. They commented that the potential effect of value losses associated with sapstain following in-forest debarking warranted further research. As noted at the beginning of this report, our set of trials also assessed the incidence and severity of sapstain and insect infestation. The results of the sapstain and insect research will be given in a following report.

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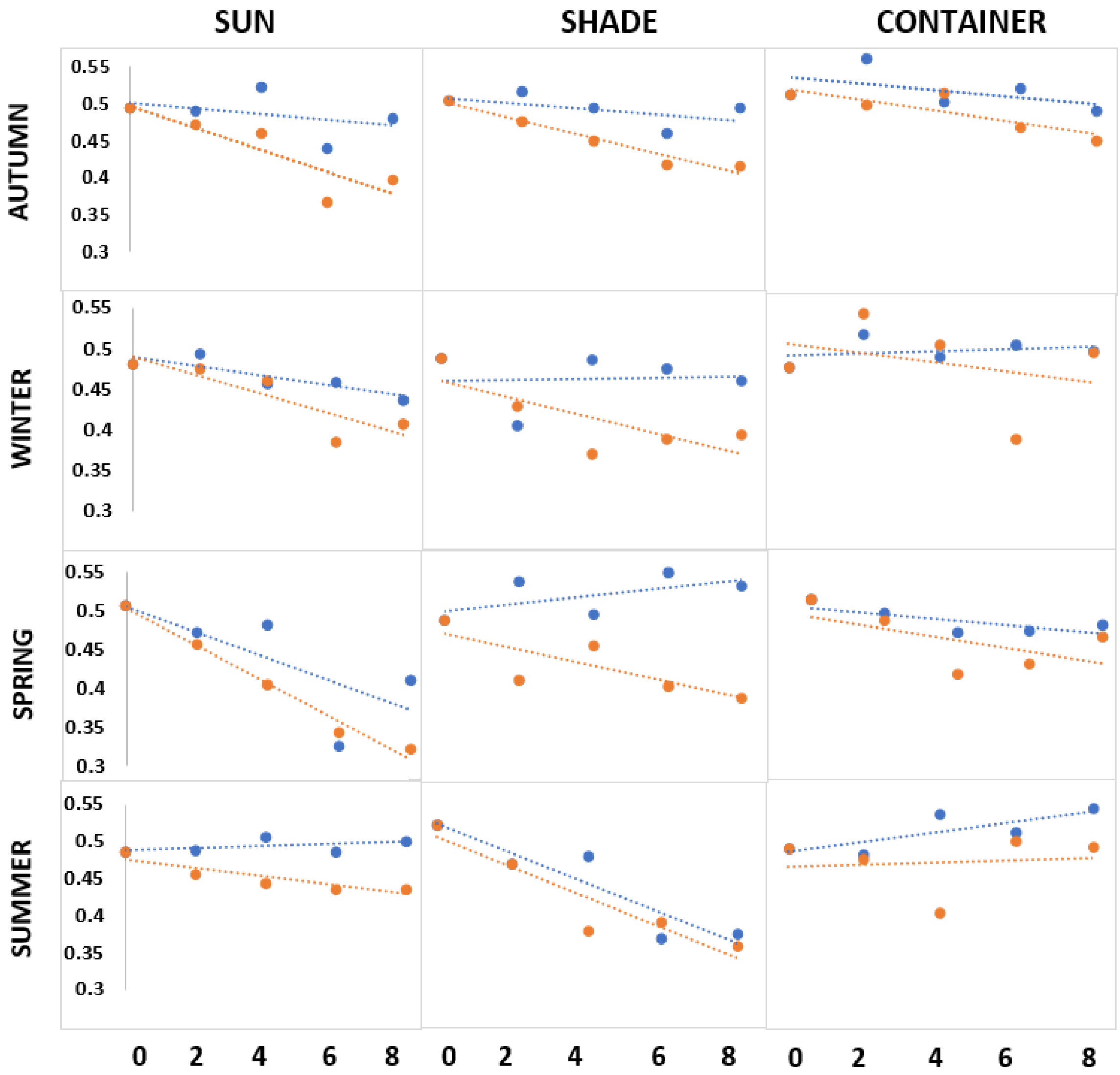
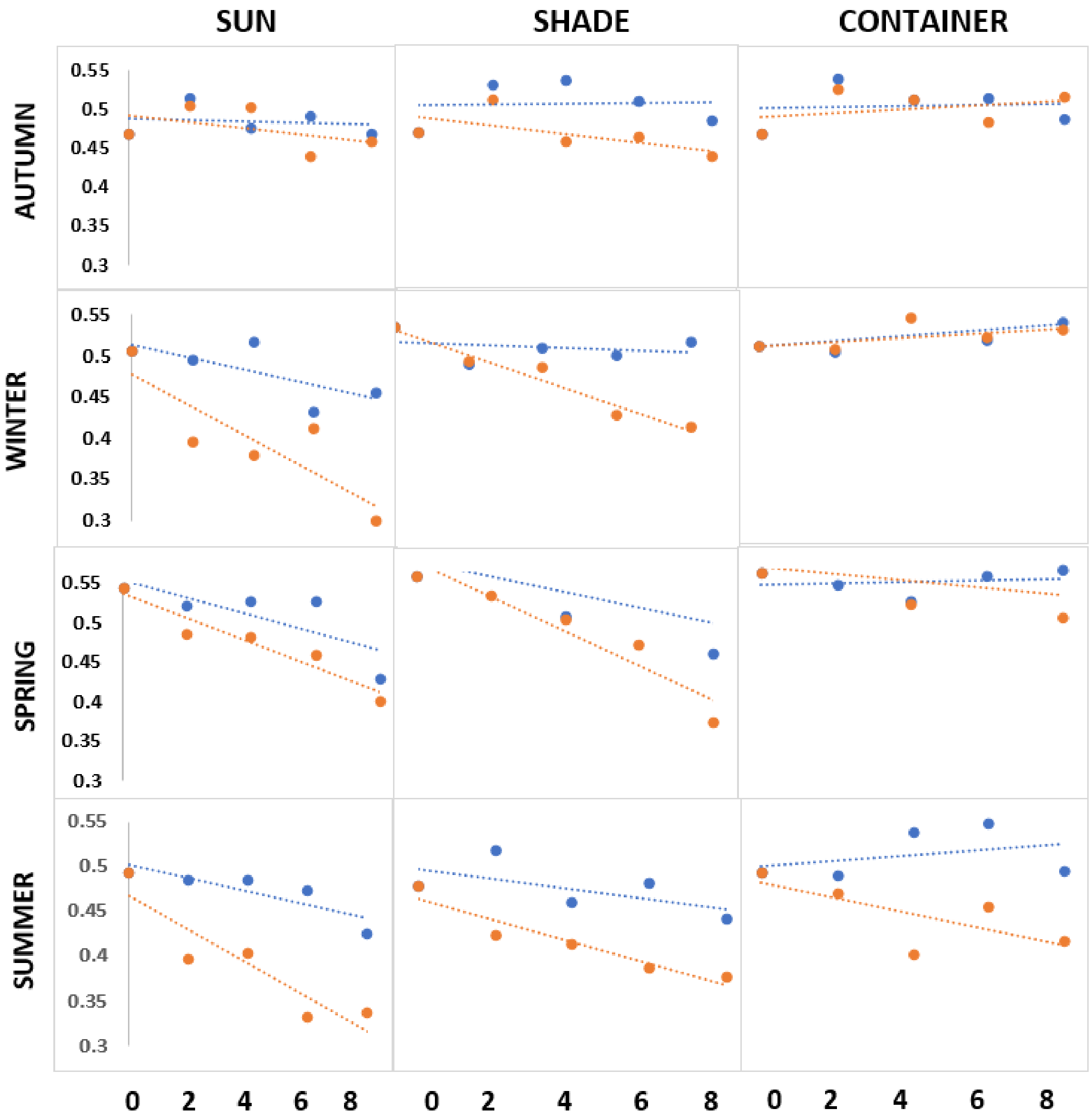
Appendix 1: Graphs depicting drying of F2 Hybrid pine and Hoop pine logs in Queensland

F2 Moisture content of discs with bark on (blue) and bark off (orange) for samples from harvest (0) to two months, sampled fortnightly for logs stacked in sun, shade or a shipping container over four seasons. Y-axis is proportion of mass that is water, x-axis is number of weeks since felling.



Hoop pine Moisture content of discs with bark on (blue) and bark off (orange) for samples from harvest (0) to two months, sampled fortnightly for logs stacked in sun, shade or a shipping container over four seasons. Y-axis is proportion of mass that is water, x-axis is number of weeks since felling.



Productivity and Costs of Container Handling and Loading in Log Yards

Prepared for

Forest & Wood Products Australia

by

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Executive summary

Repositioning empty containers from container surplus to container deficit regions around the world is a large operational cost for shipping companies. The opportunity to backload logs, in what would have been empty containers otherwise, is attractive to some shipping companies and competitive shipping prices can be offered.

This publication provides an international review of container handling and loading systems in log yards and presents case studies of container log loading systems that are currently operational on the east coast of Australia. The case studies relate to softwood log exports from plantation forests.

A web-based review indicated that there is a wide range of systems being used for loading logs into containers. These range from simple, low capital cost, labour intensive systems to higher capital cost, purpose-built loading machines. The movement of empty and loaded containers around the log yard, along with storage areas for the containers, is a significant time and cost element.

The three case studies and two additional simulated systems included in the analyses indicated that productivity (range = 3.8 to 7.7 containers per hour) and unit costs (range = \$4 to \$10 per JAS m^3 [excluding unloading of logs from trucks and scaling costs) can be expected to vary due to, among other things, differences in system configurations, lengths of logs being handled, target container weight limits, and species.

Damage to containers was cited by log yard owners as being a potential issue for some loading systems. The costs of container damage were not studied or included in this report.

Table of Contents

Executive Summary i
Introduction 1
International Review of Container Loading Systems 1
Case Studies of Container Handling and Log Loading Systems 8
  Case Study 1 9
  Case Study 2 14
  Case Study 3 19
System Comparisons 24
Conclusions 26

Introduction

In 2016 global industrial roundwood production amounted to 1874 million m^3 (FAO 2017). Approximately 7% of this production (132 million m^3) was exported in roundwood form. Australia was the sixth largest log exporter (3.9 million m^3).

Although no exact numbers are available most logs are shipped and exported in bulk, or loose, form. A relatively small proportion is exported in containers.

Regional trade imbalances, however, mean that many shipping companies are faced with repositioning empty containers from container surplus to container shortage locations. For example, one of the world's largest shipping companies is faced with repositioning 900,000 empty TEU's (20-foot equivalent container units) annually to cover uneven regional demand for containers. Repositioning empty containers is this shipping company's largest operational cost after ship fuel (Epstein et al. 2012).

The opportunity to backload logs, in what would have been empty containers otherwise, is attractive to some shipping companies and competitive shipping prices can be offered. The other big benefit for both exporters and importers is that small lots of just a few hundred cubic meters can be delivered and the exporter isn't restricted to the main ports that can handle bulk logs. This opens up the market to niche buyers and sellers serviced by more ports (Weblin 2008). Gains in forest gate returns of up to \$10 per JAS m^3 have been reported.

This publication provides an international review of container handling and loading systems in log yards and presents three case studies of container log loading systems that are currently operational on the east coast of Australia. The case studies relate to softwood log exports from plantation forests. Two additional log loading systems are simulated and included in the system comparisons.

International Review of Container Log Loading Systems

A search of the web was carried out to determine what types of equipment and systems were being used to load logs into, and unload logs out of, containers. More information was available on loading than unloading logs from containers. Web-links to videos are provided where they are available.

Loading single logs (or small bunches of logs) with a boom loader

A number of videos were found showing single logs, or small bunches of logs, being loaded by a boom loader into containers that were either sitting on the back of a waiting truck (Figure 1, see also www.youtube.com/watch?v=kxkVROKO9I4 ; www.youtube.com/watch?v=l13Ft5YR69I ; vimeo.com/210834297;) or on the ground (Figure 2, see also www.youtube.com/watch?v=bHrQB41EK1c ; www.youtube.com/watch?v=MvC3FW7rSiM ; www.youtube.com/watch?v=sC6yCJiUSvQ).

In some cases, logs are fully inserted into the container by the loader. In other cases, the loader partially inserts the logs into the container and then an additional machine is used to push the logs the rest of the way into the container (Figures 3, 4 and 5).

Figure 1. Loading of single logs with a truck-mounted boom loader (left) and multiple logs with an excavator loader (right) into containers on the back of waiting trucks.

Figure 2. Loading of single logs into a container resting on the ground with an excavator loader.

Figure 3. A rubber tyred front-end loader pushes protruding logs the rest of the way into the container using its loading forks.

Figure 4. A pusher plate on the end of a boom loader being used to push protruding logs into a container.

Figure 5. A detachable pusher plate that is held in the forks of a rubber-tyred loader and used to push protruding logs into a container.

Times taken from video footage indicate an average time of about 0.60 minutes per log to load containers using these methods.

Loading single logs with a crane and temporary gantry

Figure 6 (see also www.youtube.com/watch?v=eZ3AJoAbseg) shows a single log, suspended from an overhead gantry that has been temporarily erected inside the container. The log is being manually pushed to the back of the container where it is lowered and released. The log was moved to the edge of the container in a sling suspended from a crane and then transferred to a second sling suspended from the overhead gantry. The overhead gantry can be later used to empty the container, one log at a time.

Figure 6. Manual pushing of a single log suspended from a temporarily erected overhead gantry inside a container.

Loading single logs (or small bunches of logs) with forklifts and attachments

Figures 7, 8 and 9 (see also www.youtube.com/watch?v=3Mj8NXhu2Co ; www.youtube.com/watch?v=1Y7brWlWI5M ; www.youtube.com/watch?v=aLsjjgXhxEE) show logs being loaded into containers with forklift loaders with different types of attachments. The forklifts are small enough to drive into and place logs at the back of the container.

Figure 7. Forklift with a grapple attachment loading single logs into a container resting on the ground.

Figure 8. Forklift with a pincer attachment being used to load multiple logs into a container resting on the ground.

Figure 9. Forklift with a ring attachment being used to load logs into a container on the back of a waiting truck.

Times taken from video footage indicate an average time of about 0.58 minutes per log to load containers using these methods.

Loading pre-bundled logs with a crane

Figure 10 (see also www.youtube.com/watch?v=1MVY3mxB1tw) shows a pre-bundled load of logs suspended in slings and about to be loaded into a container. Once the front ends of the logs are supported by the container base the slings are slackened and the logs are pushed into the container with a bucket loader.

Figure 10. Pre-bundled logs, suspended from a crane, being loaded into a container on the back of a waiting truck.

Loading pre-bundled logs on pallets with a forklift

Figure 11 (see also www.youtube.com/watch?v=XAwj8qXOXhM) shows a pre-bundled load of logs about to be loaded into a container with a forklift. The forklift has very long prongs that cover the full length of the container. Times taken from the video indicate loading times of 0.96 minutes (beings at logs in front of the container, ends when the prongs are removed) and unloading times of 1.05 minutes (begins with prongs in front of the container, and ends when the prongs are removed). For the log load shown in the video these equate to 0.11 and 0.12 minutes per log respectively for loading and unloading but it should be noted that these times do not includes times for all of the loading and unloading activities.

Figure 11. Pre-bundled logs on pallets being loaded with a forklift into a container resting on the ground.

Loading logs into containers from cradles

Figure 12 (see also www.youtube.com/watch?v=89DI5CQD-Ls) shows logs being loaded into a cradle. The logs are then pushed from the cradle into the container by a front-end loader with a pusher plate.

Figure 12. Logs being loaded by a front-end loader into a cradle positioned in front of a container on the back of a waiting truck (left). Logs from the loaded cradle are then pushed into the container by a front-end loader with a pusher plate (right).

Loading logs from purpose-built container loaders

Figures 13 (see also www.youtube.com/watch?v=I6USU9uZ204 ; www.youtube.com/watch?v=-0GSwaXJCHI ; www.youtube.com/watch?v=BIe_bJCi1-A) shows logs being loaded into a purpose-built container loading frame. The truck backs up to the frame which includes a ram with a pushing plate that transfers the load of logs from the frame into the container. Some loading frames include weight scales to minimize the chance of the container being overloaded. Times taken from one video indicated loading times of 3.6 minutes to load the frame with 27 tonnes of logs and then 5.78 minutes to transfer logs from the frame to the container.

Figure 13. Logs being loaded into a loading frame which contains a pusher plate to transfer the logs into the container on the back of a waiting truck.

Unloading logs from containers

As noted above not much information is available on unloading of logs from containers. Figures 6 and 11 showed approaches that could be used for unloading as well as loading containers. Figures 14 (see also www.youtube.com/watch?v=F5S9kVmvzCA) shows logs being dragged from a container using wire rope and a front-end loader. One manufacturer of purpose-built container loaders also suggested lifting the container with a large crane and tipping the logs out of the container.

Figure 14. A large log being dragged out of a container by one front-end loader while another front-end loader supports the log.

Case Studies of Container Handling and Log Loading Systems

Three case studies were carried out of container handling and log loading systems in log yards operating in eastern Australia in March and April 2018. For commercial sensitivity reasons, the locations and operators of the log yards are not provided.

The productivity of each container handling and log loading system was studied using time study techniques for short durations of one to two days each. The movement of containers around the log yard and the loading of containers was studied. Unloading of logs from trucks and log scaling activities were not studied. Net load weights, volumes and log grade information were obtained from the companies participating in each case study.

Unit costs ($ per tonne or $ per JAS m^3) were determined for each system (excluding unloading of trucks and log scaling) based on calculated[1] hourly costs for labour and for new machines using standard machine costing procedures and assumed machine lives.

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[1] Note that the companies participating in the studies were not asked to supply their hourly costs. The calculated costs, therefore, may or may not relate to actual costs

Case study 1

Description of operation

The Case Study 1 log yard handles approximately 5200 containers per year (~125,000 m^3) on an area of about 1.5 ha. Space at the site is allocated to office and equipment parking, log inflow and storage, empty container storage, container packing, container fumigation, loaded container storage and traffic areas. Container loading operations take place 5 days per week, 12 hours per day.

Araucaria and pine logs are delivered to the log yard by trucks. After arriving logs are unloaded with front-end loaders, tagged, scaled on the ground, and then stored in rows.

A front-end loader (Caterpillar 980G or Volvo 180F) moves logs from the rows to the container packing area. An excavator loader (Caterpillar 320D) or materials handler (Sennebogen 730) places bunches of logs, and sometimes single logs when the container is nearly "full", partly into the container (Figure 15). Protruding logs are then pushed into the container by a front-end loader with a detachable pusher plate (Figure 16.)

Containers are 12 m (40 ft) in length. Logs loaded into the containers are usually either 3.8 m nominal lengths (in which case 3 lots of 3.8 m logs will be loaded) or 5.8 m nominal lengths (in which case 2 lots of 5.8 m logs will be loaded). Logs being loaded into containers are counted and have their bar codes scanned. Containers reach their weight limit before they reach their volume limit (Figure 17).

Loaded containers are then moved to the fumigation area by a container handler (Kalmar DRF450) (Figure 18) where the logs are fumigated for 24 hours. From there the containers are moved to the container storage area by the container handler. Loading and unloading of containers on trucks is also undertaken by the container handler.

Figure 15. Logs being partially loaded into a container with an excavator loader.

Figure 16. A front-end rubber loader with a detachable pusher plate that are used to push logs into a container resting on the ground.

Figure 17. The two containers on the left and right of the photo are “full”, having reached their maximum allowable weight limit.

Figure 18. Containers are moved around the log yard by a container handler.

Time studies

Weight, volume and log counts

Weight, volume and log count data were collected for 53 container loads of logs. There were little differences in either average net weight or volume between Araucaria and pine container loads. As expected, there were differences, however, in the log counts per container load depending on log lengths and grades (Table 1).

Table 1. Weight, volume and log count statistics

Genus	Length (m)	Log counts				Volume per container (JAS m^3)	Weight per container (tonnes)
		All Grades	A grade	U1 grade	U3 grade		
Araucaria	3.8	80.3	59.6	109.2	-	-	-
	5.8	70.4	-	57.1	123.5	-	-
	Combined	75.8	-	-	-	22.09	25.85
Pinus	3.8	80.7	39.0	101.5	-	-	-
	5.8	64.5	-	64.5	-	-	-
	Combined	66.1	-	-	-	21.34	25.99
Both Araucaria and Pinus	Combined	70.1	-	-	-	21.59	25.94

Container unloading from trucks and container loading onto trucks

Times were gathered for the Kalmar DRF450 container handler unloading 9 empty containers from trucks and loading 35 full containers onto trucks. The distances the containers were moved from or to the trucks ranged between 20 and 70 metres (average ~ 50 m). There was no statistically significant relationship (p = 0.05) between the times and the distances the containers were moved. There was also no statistically significant difference between unloading and loading times.

The average time for unloading empty containers was 1.96 minutes per container and the average time for loading full containers was 1.96 minutes per container.

Moving empty containers to the packing area

Times were gathered for the Kalmar DRF450 moving 25 empty containers to the container packing area. The average move empty container time was 2.41 minutes per container.

Distances ranged between 20 and 140 metres (average ~ 76 m). Distance was found to be a statistically significant predictor of moving time.

$$\textit{Empty container moving time (minutes)} = 1.92 + 0.006 * \textit{Distance}$$
$$R^2 = 0.25$$

Three short delays occurred while timing was being carried out. These were due to difficulties positioning a container, difficulties determining the container identification number and congestion in the container packing area. Pro-rated delays were calculated to be 0.04 minutes per container.

Moving logs from rows to the packing area

Times were gathered for moving 75 bundles of logs from the rows to the container packing area to fill 26 container loads in total; 18 container loads were supplied with logs using the Caterpillar 980G and 8 container loads using the Volvo 180F. The average time for moving logs from rows to the packing area was 4.36 minutes per container.

Distances from the rows to the packing area ranged between 20 and 100 metres (average ~ 35 m). Distance was not found to be a statistically significant predictor of time per container.

The number of bundles per container (range = 2 to 5, average = 2.88) and number of logs per container (range = 49 to 122) were both found to be statistically significant predictors of time required to move logs from rows to the packing area.

$$\textit{Moving logs to packing area (minutes)} = -5.86 + 1.82*\textit{Number of bundles} + 0.073*\textit{Number of logs}$$

$$R^2 = 0.62$$

The number of logs per container is related to log lengths and grades (see Table 1). The number of bundles per container were not related to lengths or grades.

Nineteen production delays occurred while timing was being carried out. These were mainly due to log position and log weight adjustment problems and waiting for another machine to move out of the way. Pro-rated delays were calculated to be 0.67 minutes per container.

Partial loading of logs into the container

Times were gathered for the Sennebogen 730 partial loading of 149 grabs of logs into 27 containers. The average loading time was 8.71 minutes per container.

The number of grabs per container ranged from 4 to 8 but was not found to be a statistically significant predictor of loading time.

Fifty-seven production delays were recorded during the loading of the continues. The most time-consuming delays were reloading the front portion of a container (48% of delay time), cleaning debris from the packing area (22%). and waiting for another machine (17%). Pro-rated delays were calculated to be 4.24 minutes per container.

Pushing logs into the container

Times were gathered for the Caterpillar 980G pushing logs into 26 containers. The average pushing time was 1.92 minutes per container.

Pushing time was not related to the number of logs being loaded or the load volume. It was, however, related to the number of pushes required per container; 3.00 pushes per container for

3.8 m logs, and 2.05 pushes per container for 5.8 m logs. Pushing time per container was 2.56 minutes for 3.8 m logs and 1.77 minutes for 5.8 m logs.

Pro-rated delays were calculated to be 0.06 minutes per container.

Container information recording time

Times were gathered for the recording of information related to 26 containers. The average recording time was 0.92 minutes per container.

Moving loaded containers to the fumigation area

Times were gathered for the Kalmar DRF450 moving 25 loaded containers to the fumigation area. The average move time was 2.24 minutes per container.

Neither distance (range = 30 to 80 m, average 60 m), nor load volume (range 16.67 to 24.41 m^3) were statistically significant predictors of moving time to the fumigation area.

Delays were few. Pro-rated delays were calculated to be 0.03 minutes per container.

Productivity and cost estimates

Productivity calculations for the system are shown in Table 2. Loading logs for packing with the Sennebogen 730 was the limiting activity, giving a calculated productivity of 4.1 containers per hour.

For a 12-hour scheduled work day the calculated productivity is equivalent to 49.2 containers per day.

Calculated productivity per scheduled hour, based on average container weights and volumes, can also be expressed as 106.4 tonnes per hour or 88.4 JAS m^3 per hour. Although log length affected some activities it did not affect the limiting activity so these calculated productivity estimates are not sensitive to this variable.

Estimated hourly costs[2] for the system are $627. These costs exclude equipment and labour for unloading of logs and log scaling. They include costs for the Caterpillar 980G front-end loader, the Kalmar DRF450 container handler, the Sennebogen 730 materials handler, three machine operators and ground person, overheads and profit margin.

Combining calculated productivity estimates and estimated hourly costs gives unit costs for container handling and loading of $153 per container or $7.09 per JAS m^3 or $5.89 per tonne.

The company undertaking the container loading activities commented that when things go well they average 35 to 40 containers per day. Two possible scenarios could account for this; (1) hourly productivity was higher than normal during the study, or (2) the assumed system utilisation level (75%) was too high for this operation. Reducing the daily production to 37.5 containers would equate to a cost of about $9.30 JAS m^3.

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[2] As noted earlier in the report these costs are calculated and not based on actual costs of container loading company.

Table 2. Calculated productivity in Case Study 1 log yard based on observed activities

Activity	Machine	Time (minutes per container)	Productivity (containers per PMH$_{15}$[3])	Productivity (containers per SMH[4])
Unload empty containers from truck	Kalmar DRF450	1.96		
Move empty containers to packing area		2.47		
Move full containers to fumigation area		2.27		
Load full containers onto truck		1.96		
Sub-total		8.66	6.9	5.2
Move logs from rows to packing area	Cat 980G	5.03		
Push logs into container		1.98		
Sub-total		7.01	8.6	6.4
Load logs for packing	Sennebogen 730	10.97	5.5	4.1
Recording container information	-	0.92	65.5	49.2
Calculated productivity based on limiting machine/person			5.5	4.1

Case study 2

Description of operation

The log yard is located adjacent to a rail line. Empty and full containers arrive at and leave the yard by rail. Space in the ~ 2.5 ha yard is allocated to (a) the weighbridge office and equipment parking, (b) log scaling and storage [is split over several locations around the edge of the site, (c) empty container storage, (d) container packing, (e) container fumigation, and (f) loaded container storage. Designated areas for the packing, fumigation and container storage areas are not fixed.

Pine logs are delivered to the log yard by truck. On arrival at the site, logs are weighed on the weighbridge, unloaded from the trucks, scaled and then put into their designated rows where they remain until night-time. Container packing is done at night, 5 days per week, during a 10 to 12-hour shift.

During the night-shift logs are picked up from the designated rows by a Volvo 180 front-end loader and moved to a cradle located near the end of the row (Figure 19). Logs are added to

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[3] Productive machine hour (includes delays of 15 minutes or less)

[4] Schedule machine hour assuming 75% utilization (includes rest breaks, delays, refuelling, maintenance, etc.).

the cradle until the maximum allowable weight is reached for the particular log length and type. A person then counts the logs and scans the tickets on the logs in the cradle.

Figure 19. Cradle used for building packets of logs for insertion into containers.

The cradle is moved to in front of the container on the loading pad by a Kalmar forklift. A front-end loader with a pusher plate (Figure 20) then pushes the logs from the cradle into the container. The cradle is then moved back to the log stack. The process is repeated until the container is full. A photo is then taken of the loaded container. The container is then fumigated in situ for 24 hours.

Containers are 12 m (40 ft) in length. Logs loaded into the containers are usually either 3.8 m nominal lengths (in which case 3 lots of 3.8 m logs will be loaded) or 5.8 m nominal lengths (in which case 2 lots of 5.8 m logs will be loaded).

Empty and loaded containers are moved around the yard with either a Kalmar or Omega container handler. The container handlers also unload empty containers and load full containers onto rail wagons as required. Loading 30 containers per day is the goal for the operation.

Figure 20. Detachable pusher plate used to push logs from the cradle into containers.

Time studies

The operation in the log yard was only studied during the night shift. Activities that are mainly carried out during the day (e.g. unloading empty containers from rail wagons, loading full containers onto rail, and moving empty containers around the yard) were not studied.

Weight, volume and log counts

Weight, volume and log count data were collected for 25 container loads of logs (Table 3). Container net weights and volumes are greater for Case Study 2 than Case Study 1 (and Case Study 3) since the loaded containers are removed from the log yard by rail. Maximum load limits are greater on rail than on public roads.

Table 3. Weight, volume and log count statistics

Length (m)	Log counts			Volume per container (JAS m^3)	Weight per container (tonnes)
	All Grades	A grade	K grade		
3.8	100.0	68.7	137.6	28.50	28.40
5.8	41.3	41.3	-	27.96	28.10
Combined	67.1	-	-	28.20	28.23

Moving logs from rows to the cradles

Times were gathered for moving 133 bundles of logs from the rows to 61 cradles using the Volvo 180. The cradles were later moved to 25 containers. The average time for moving logs from rows to the cradles was 4.71 minutes per container (excluding delays).

Distances between rows and cradles averaged 44 metres (range 20 to 50 m). The number of cradles loaded per container averaged 2.44 (range 2 to 3). Neither distance nor number of cradles per container were statistically significant predictors of time for moving logs from row to the cradles.

Seven production delays occurred during timing. These were associated with adjusting of logs within the cradles. Pro-rated delay time for this activity was 0.09 minutes per container.

Moving loaded cradles to the containers

Times were gathered for moving 61 loaded cradles to 25 containers using the Kalmar forklift. The average time was 6.47 minutes per container (excluding delays).

Distances between the cradle loading positions and containers averaged 38 metres (range 20 to 60 m). Distance was not a statistically significant predictor of time per container for moving cradles.

As noted above, the number of cradles moved per container averaged 2.44. Two cradles were moved for 5.8 m long logs and three cradles were moved for 3.8 m logs. The number of cradles per container was a statistically significant predictor of time for moving cradles to the container.

$$\textit{Moving cradles to containers (minutes per container)} = 4.15 + 0.95 * \textit{Number of cradles}$$

$$R^2 = 0.18$$

Two production delays occurred during timing. These were associated with adjusting log heights and cradle weights. Pro-rated delay time for this activity was 0.14 minutes per container.

Pushing logs into the container

Times were gathered for the Volvo 180 pushing logs into 25 containers. The average pushing time was 2.34 minutes per container (excluding delays).

Pushing time was related to the number of pushes required per container; 3 pushes per container for 3.8 m logs, and 2 pushes per container for 5.8 m logs. Pushing time per container was 2.80 minutes for 3.8 m logs and 2.27 minutes for 5.8 m logs.

Six production delays occurred during timing. These were associated with difficulties closing the container door and pushing of cradles. Pro-rated delay time for this activity was 0.16 minutes per container.

Productivity and cost estimates

Productivity calculations for the system are shown in Table 4. Moving logs for row to cradles and pushing logs into containers with the Volvo 180 was the limiting activity, giving a calculated productivity of 6.2 containers per hour. It should be noted that, since times were not gathered in Case Study 2 for unloading and loading containers from and onto rail wagons, or moving empty containers around the site, times used in Table 4 for these activities have been assumed to be the same as those found for Case Study 1.

Table 4. Calculated productivity in Case Study 2 log yard based on observed activities

Activity	Machine	Time (minutes per container)	Productivity (containers per PMH$_{15}$)	Productivity (containers per SMH)
Unload empty containers from rail wagon	Omega container handler	1.96		
Move empty containers to packing area		2.47		
Load full containers onto rail wagon		1.96		
Sub-total		6.39	9.4	7.0
Move logs from rows to cradles	Volvo 180	4.80		
Push logs into containers		2.50		
Sub-total		7.30	8.2	6.2
Move cradles to containers	Kalmar forklift	6.61	9.1	6.8
Recording container information	-	0.92	65.5	49.2
Calculated productivity based on limiting machine/person			8.2	6.2

For a 11-hour scheduled work day the calculated productivity is equivalent to 67.8 containers per day. Calculated productivity per scheduled hour, based on average container weights and volumes, can also be expressed as 174.0 tonnes per hour or 173.8 JAS m^3 per hour.

Estimated hourly costs[5] for the system are $617. These costs exclude equipment and labour for unloading of logs and log scaling. They include costs for the Volvo 180 front-end loader, the Omega container handler, the Kalmar forklift, three machine operators and ground person, overheads and profit margin.

Combining calculated productivity estimates and estimated hourly costs gives unit costs for container handling and loading of $100 per container or $3.55 per JAS m^3 or $3.54 per tonne. Log length affected the time to move cradles to the containers and the time to push logs into the containers. Log length was found to effect system productivity and costs. The estimated unit costs for container handling and loading was $3.52 and $3.79 per JAS m3 for 5.8 m and 3.8 m long logs respectively.

The calculated daily productivity is substantially higher than the company goal of 30 containers per day. The reason for the large difference is unknown but may be due restrictions in supply of logs or in fumigation storage capacity. Daily production of 30 containers a day would equate to unit costs of about $8.00 per JAS m^3.

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[5] As noted earlier in the report these costs are calculated and not based on actual costs of the container loading company.

Case study 3

Description of operation

Container loading activities are carried out on an area of approximately 2.0 ha in Case Study 3. Pine logs are delivered to the log yard by truck. On arrival at the site, logs are unloaded from the trucks, scaled and then put into their designated rows. Container packing is done 5 days per week during a 10.5-hour shift.

Empty containers are moved to the packing area by a Hyster 45-31CH container handler. The container handler then waits until the container is loaded.

Logs are picked up from the designated rows by a Volvo or Liebherr front-end loader and moved to a fixed cradle (Figure 21) situated in front of a permanently located hydraulic ram. Once the cradle is loaded the packet of logs is pushed into the container using the hydraulic ram (Figure 22). The process is repeated until the container is full.

Container details are then recorded and the full container is moved by the container handler to a fumigation area (Figure 23).

Containers are 12 m (40 ft) in length. Logs loaded into the containers are either 3.8 m nominal lengths (in which case 3 lots of 3.8 m logs will be loaded) or 5.8 m nominal lengths (in which case 2 lots of 5.8 m logs will be loaded). Similar to the other two case studies, containers reach their weight limit before they reach their volume limit (Figure 24).

Empty and loaded containers are moved around the yard with a second Hyster 18.00-12EC container handler. The Hyster also unloads empty containers and loads full containers onto trucks as required.

Figure 21. Volvo 180E front end loader loading logs into the packing cradle.

Figure 22. Logs being pushed from the cradle into the container by the hydraulic ram.

Figure 23. Full containers are moved to a fumigation area by a container handler.

Figure 24. Containers reach their weight limit before space in the container is fully occupied.

Time studies

Activities that were studied in the Case Study 3 log yard were moving containers to and from the packing area, loading of logs in the packing cradle, and pushing of logs into containers by the hydraulic. Other activities that are necessary for container handling and packing (e.g. unloading empty containers from trucks, loading full containers onto rail, and moving empty containers around the yard) were not studied. Similar to the other two case studies, unloading of trucks and log scaling were not considered in the study.

Volume and log counts

Volume and log count data were collected for 32 container loads of logs (Table 5). Weights were not recorded.

Table 5. Volume and log count statistics

Length (m)	Log counts				Volume per container (JAS m^3)
	All Grades	A grade	U1 grade	U3 grade	
3.8	115.3	54.0	113.3	266.0	26.73
5.8	77.5	31.2	66.8	141.8	26.08
Combined	97.6	36.9	102.9	162.5	26.43

Moving logs from rows to the packing cradle

Times were gathered for moving 112 bundles of logs from the rows to 32 containers using the Volvo 180. The average move distance was 70 m. The number of bundles per container was dependent on the log lengths put into the container; average of 3.88 for 3.8 m logs and 3.13 for 5.8 m logs. The average time for moving logs to the container was 9.35 minutes per container. This was also dependent on log length; 10.35 minutes per container for 3.8 m logs and 8.36 minutes per container for 5.8 m logs.

Many delays were noted during the time study. These were allocated to three categories; operational delays (e.g. waiting for other machines to be ready) which accounted for 2.62 minutes per container, container information recording delays which accounted for 0.28 minutes per container, and other delays (e.g. changing machine operators) which accounted for 0.72 minutes per container.

Pushing logs into containers

Times were gathered for pushing logs with the hydraulic ram into 33 containers. The average pushing time was 7.24 minutes per container (excluding delays).

Pushing time was related to the number of pushes required per container; 3 pushes per container for 3.8 m logs, and 2 pushes per container for 5.8 m logs. Pushing time per container was 7.90 minutes for 3.8 m logs and 6.54 minutes per container for 5.8 m logs.

The log yard owner commented that the return valve on the hydraulic ram was blocked during the study. The machine was designed to push at 12.5 seconds per m and return at 7.0 seconds per m. During the trial the times were 15.7 and 15.4 seconds per m. Based on the design specifications we would expect the average total design push time to be 79% of the observed time. This would equate to 5.71 minutes per container on average, or 6.24 minutes for 3.8 m logs and 5.17 minutes for 5.8 m logs.

Production delays were few for this activity. Pro-rated delay time for this activity was 0.04 minutes per container.

Moving containers to and from the packing area

Times were gathered for the Hyster container handler moving 33 containers to and from the packing area. The average move distance was 60 m (range = 30 to 125 m). The average time (excluding delays) was 11.71 minutes per container.

This was made up of (a) moving the empty container to the packing area, opening it and locating it in front of the packing cradle (3.08 minutes per container), (b) picking up the container, closing it and moving it to the storage area (3.36 minutes per container), and (c) waiting for the hydraulic ram (5.76 minutes per container for 3.8 m logs and 4.75 minutes per container for 5.8 m logs).

Fourteen additional delays occurred for this activity during time. Pro-rated delay time was 0.98 minutes per container.

Productivity and cost estimates

Productivity calculations for the system are shown in Table 6. Moving logs from rows to the packing cradle with the Volvo 180 was the limiting activity, giving a calculated productivity of 3.8 containers per hour. It should be noted that, since times were not gathered in Case Study 3 for unloading and loading containers from and onto trucks, or moving empty containers around the site, times used in Table 6 for these activities have been assumed to be the same as those found for Case Study 1.

For a 10.5-hour scheduled work day the calculated productivity is equivalent to 40.0 containers per day. Calculated productivity per scheduled hour, based on average container volumes, can also be expressed as 100.8 JAS m^3 per hour.

Estimated hourly costs[6] for the system are $919. These costs exclude equipment and labour for unloading of logs and log scaling. They include costs for the Volvo 180 front-end loader, the two Hyster container handlers, the hydraulic ram, four machine operators and a ground person, overheads and profit margin.

Combining calculated productivity estimates and estimated hourly costs gives unit costs for container handling and loading of $241 per container or $9.12 per JAS m^3. Log length affected the time for all of the activities studied, however moving logs to the packing cradle remained the limiting activity regardless of whether 3.8 m or 5.8 m logs were being loaded. The estimated unit costs for container handling and loading was $8.41 and $9.81 per JAS m^3 for 5.8 m and 3.8 m long logs respectively.

Table 6. Calculated productivity in the Case Study 3 yard based on observed activities

Activity	Machine	Time (minutes per container)	Productivity (containers per PMH_{15})	Productivity (containers per SMH)
Unload empty containers from truck	Hyster container handler	1.96		
Move empty containers to packing area		2.47		
Load full containers onto truck		1.96		
Sub-total		6.39	9.4	6.3
Move logs from rows to cradle	Volvo 180	12.97	4.6	3.1
Move containers to and from hydraulic ram*	Hyster container handler	11.58	5.2	3.5
Push logs into container*	Loginator	5.75	10.4	7.0
Recording container information	-	0.92	65.5	44.2
Calculated productivity based on limiting machine/person			4.6	3.1

* Observed times have been reduced to account for the hydraulic ram return cylinder misfunctioning while the study was being undertaken.

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[6] As noted earlier in the report these costs are calculated and not based on actual costs of the container loading company.

The calculated daily productivity is slightly lower than the productivity regularly achieved by the company; i.e. 40 to 44 containers per day. Daily production of 42 containers a day would equate to unit costs of about \$8.69 per JAS m^3.

System Comparisons

Five container handling and loading systems are compared below (Table 7); the three systems described and studied in the three case studies and two additional systems based on simulations of equipment seen in the case studies and in videos on the internet.

Simulated system 4 is comprised of a front-end loader for moving logs from rows to the packing area, 4 forklifts with grapples for loading logs into containers (similar to Figures 7 and 8), a container handler for moving containers around the site, six operators and a ground person.

Simulated system 5 is comprised of a front-end loader for moving logs from rows to the packing area, a mobile loading frame (similar to Figure 13), two container handlers for moving containers around the site, four operators and a ground person.

Comparisons are made in terms of tonnes per hour, JAS m^3 per hour, and estimated unit costs. Container load volumes (25.0 JAS m^3) and weights (27.5 tonnes) have been standardised to remove differences between log grades, species, localities and onwards container transport systems.

Productivity for Case Studies 1 and 3 were similar (3.8 to 4.1 containers per hour), each having the same limiting activity (i.e. moving logs to from rows to the packing area) and time for that activity. Costs for Case Study 1 were lower due to it requiring one less container handler and having a simpler (lower cost) system for pushing logs into containers.

Productivity for Simulated System 4 was between Case Studies 1 and 3 (4.0 containers per hour). Loading of logs into the containers was the limiting activity. Four forklifts were required to achieve this level of productivity. Calculated costs also sat between those of Case Studies 1 and 3; the cost of the forklifts was comparatively low but additional operators were required.

Productivity for Case Study 2 was calculated to be 6.2 containers per hour. Moving logs from rows to cradles and pushing logs into the container were the limiting activities. Fewer pieces of equipment and less labour was required for this operation leading to low estimated unit costs.

Simulated System 5 is similar to the Case Study 3 system but had faster movement of logs to the packing area and better utilisation of the container handlers. Pushing logs into the container was the limiting activity. Despite higher productivity (7.7 containers per hour) than for Case Study 2, estimated unit costs were higher due to the need for higher capital cost equipment and more machine operators.

Table 7. Comparison of calculated productivity and costs for five container handling and log loading systems.

System	Productivity (containers per hour)	Productivity (JAS m^3 per hour)	Productivity (tonnes per hour)	Unit cost ($ per JAS m^3)	Unit cost ($ per tonne)
Case Study System 1	4.1	103	113	6.11	5.56
Case Study System 2	6.2	154	170	4.00	3.64
Case Study System 3	3.8	95	105	9.64	8.77
Simulated System 4	4.0	100	110	8.12	7.38
Simulated System 5	7.7	193	213	4.97	4.52

It should be noted that loading logs into containers can result in damage to the containers. This issue was commented on by log yard owners at each of the case study sites. Fixing or replacing damaged containers can be costly to the log yard owner. Some systems can be expected to have a lower risk of damaging containers associated with them (e.g. Case Study 3 and Simulated System 5). Damage to containers was not observed in the short duration case studies included in this report. No costs of damage to containers have been included in the above analyses.

Conclusions

Repositioning empty containers from container surplus to container deficit regions around the world is a large operational cost for shipping companies. The opportunity to backload logs, in what would have been empty containers otherwise, is attractive to some shipping companies and competitive shipping prices can be offered.

A web-based review indicated that there is a wide range of systems being used for loading logs into containers. These range from simple, low capital cost, labour intensive systems to higher capital cost, purpose-built loading machines.

The three case studies and two additional systems included in the analyses indicated that productivity and unit costs can be expected to vary due to, among other things, differences in system configurations, lengths of logs being handled, species and onward transport systems.

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Sensor technologies for volumetric measurements of logs on trucks

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by

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Executive summary

Since wood represents an important proportion of the stump-to-mill delivered costs, it is important to adopt and implement correct measurement procedures and technologies that provide better wood volume estimates of logs on trucks. Poor measurements not only impact the revenue obtained by haulage contractors and forest companies but also might affect their contractual business relationship.

The advantages of solid volume as a unit of measuring and payment for wood and chips have recently recognised by an increasing number of forest companies worldwide, many of which have commenced to embrace commercial mechanisms and implement rate systems based on volumetric measurements. At least three technologies (laser scanning, stereoscopic cameras, and photogrammetry and 3D reconstruction) have evolved and improved substantially over the last decade, providing quicker and more accurate measurements of standing trees, logs, and woodchips. The implementation of these technologies in real life operations requires that commercial mechanisms are adopted and implemented. This must also take into consideration the legal and commercial terms associated with implementing new measurement systems for payment on a volumetric basis, as well as the capital and running costs of the technology to be implemented. This is true in particular for laser scanning, which despite being a mature and more affordable technology in the forestry domain, it remains expensive to adopt and implement in operating conditions.

This document provides an extensive literature review of laser, stereoscopic and photogrammetric systems for truckload volumetric measurements. It also reports the results of study on the use of multi-view structure from motion (SfM) photogrammetry and commercial 3D image processing software that were tested as an innovative and alternative method for automated volumetric measurement of truckloads. The images were collected with a small UAV, which was flown around logging trucks transporting Eucalyptus nitens pulplogs. Photogrammetric commercial software was used to process the images and generate 3D models of each truckload. The levels of accuracy obtained with multi-view SfM photogrammetry and 3D reconstruction obtained in this study were comparable to those reported in previous studies with laser scanning systems for truckloads with similar logs and species. The deviations between actual and predicted solid volume of logs on trucks ranged between -3.2% and 3.5%, with an average deviation -0.05%. In absolute terms, the average deviation was only 0.5 m^3 or 1.7%.

Table of Contents

Executive summary i
Introduction 1
Review of sensor technologies for volumetric measurements of logs on trucks 2
    Laser Scanning systems 2
    Stereoscopic systems 8
    Photogrammetric systems 10
Volumetric measurement of truckloads through multi-view photogrammetry and 3D image processing software: Results from a research trial 13
  Methods 13
    Data collection with UAV 13
    Processing images of each truckload with 3D reconstruction software 15
    Calculating gross volume from a 3D model 16
    Measuring the truckloads for solid volume 16
    Estimating solid volume from gross volume 18
  Results 18
    Summary of the flights around logging trucks and processing of the images 18
    Processing time for the 3D reconstruction of the truckloads 20
    Summary statistics of the truckloads 21
    Estimating solid volume from gross volume 22
Conclusions and Recommendations 25
References 26
Acknowledgements 28

Introduction

In some countries, wood is usually measured by its weight, green or dry. One of the drawbacks of this method is the inherent variation in moisture content of wood and chips, and the time and cost involved for its determination in an operational context. On the other hand, measuring volume manually (with wood sticks, tapes, etc.) results in time-consuming, inconsistent and inaccurate volumetric measurements (Knyas and Maksinov 2014). Given that wood represents on average about 1/3 of the delivered cost, it is key to adopt correct measurement procedures and technologies that provide better wood volume estimates (Nylinder et al. 2008). Poor measurements will not only impact the revenue obtained by haulage contractors and forest companies but also might affect their contractual business relationship.

The advantages of solid volume as a unit of measuring and payment for wood and chips have recently recognised by an increasing number of forest companies worldwide, many of which have commenced to embrace commercial mechanisms and implement rate systems based on volumetric measurements (Nylinder et al. 2008). At least three technologies (laser scanning, stereoscopic cameras, and photogrammetry and 3D reconstruction) have evolved and improved substantially over the last decade, providing quicker and more accurate measurements of standing trees, logs and woodchips (Murphy et al. 2010, Skarlatos and Kiparissi 2012, Harwin and Lucieer 2012). All of them generate a cloud of points that can be captured and manipulated by algorithms and visual computing libraries and implemented in pieces of software developed for specific operational uses. The implementation of these technologies in real life operations requires that commercial mechanisms are adopted and implemented. These mechanisms must take into consideration the legal and commercial terms associated with implementing new measurement systems for payment on a volume basis, as well as the capital and running costs of the technology to be implemented (Schmithüsen et al. 2014).

This document begins with an extensive literature review of laser, stereoscopic and photogrammetric systems for truckload volumetric measurements. Then, a report is provided on the results from a trial conducted in Tasmania by AFORA and supported by Forico Pty Limited. The study tested multi-view SfM photogrammetry and use of commercial 3D image processing software for automated volumetric measurement of truckloads. In the literature, there are very few studies using digital imagery to assist in the calculation of volume on logs on trucks, (Sosa et al. 2015), and on piles (Kruglov and Chiryshev 2017). However, to our best knowledge, nothing has been published on the use of multi-view photogrammetry and 3D reconstruction for the volumetric measurements of log truckloads, and this study is a first attempt to determine the levels of accuracy obtained with this technology as well as its potential to be implemented in operating conditions. Thus, this study aimed to assess the combination of multi-view photogrammetry and commercial 3D image processing software as a more affordable alternative to laser scanning systems for automated volumetric measurements of log truckloads. Specific objectives included: 1. Developing a regression model to predict the solid volume of pulplogs on trucks with low-cost SfM photogrammetry, and 2. Calculating the deviations between the actual and predicted solid volume of logs on trucks.

Review of sensor technologies for volumetric measurements of logs on trucks

Laser Scanning systems

Laser scanning (LS) is one of the most important technological advancements of the last decade, which induced significant changes in the field of 3D modelling. Laser scanners use a ground-based laser to automatically measure the three-dimensional (3D) coordinates of an object's surface in a systematic order in near real-time (Murphy et al., 2010). In the past years, laser scanners were used intensively for the generation of 3D models required for diverse applications such as documentation of cultural heritage, navigation, space exploration, etc. On its initial appearance, laser technology has surpassed traditional close-range photogrammetry, because of its accuracy and automation level (Skarlatos and Kiparissi, 2012).

In the forestry space, LS is receiving attention in Europe (Thies et al. 2004), New Zealand (Anonymous 2007), and the USA (Henning and Radtke 2006) as a new approach for gathering detailed descriptions of individual stems and their locations. Interest in the technology is also expanding to other parts of the world such as South America. Work to date has mainly focused on measurement of tree and forest parameters such as diameter-at-breast-height (DBH), height, stand density, tree identification, leaf area, and canopy structural attributes, but there is also interest in combining LS technology with optimal bucking algorithms for predicting tree value and log product recoveries (Murphy 2008) and with sawing simulators for predicting sawn timber recovery (Seifert et al. 2010).

In countries like Chile and Brazil, the use of laser scanning systems has been used for automated volumetric measurements for several years. In recent years, this interest has also expanded to North America and Scandinavia, where these technologies have been mainly confined to the scanning of individual logs in sawmills (Nylinder et al. 2010).

Laser technology and the algorithms developed for volumetric calculations provide quick and more accurate measurements of standing trees, logs and woodchips (Gutzeit et al. 2011), as well as for volumetric measurements of wood truckloads while the vehicle positions itself on the weight scale or dedicated platform (Nylinder et al. 2008). Scanning laser systems for volumetric measurements of wood truckloads are based on laser technology combined with dedicated processing software that creates 3D model images of trucks to measure the exact volume of the material loaded in a truck or trailer bin. The range finder lasers used in the scanning systems are of the highest quality, and usually, they pass the stringent metrological and accuracy testing required for trade approval. They measure the volume and biometrics characteristics of logs, woodchips, and biomass on vehicles with high precision, speed and reliability.

The five working phases of a common laser scanning unit for volumetric measurement of truckloads are presented in Figure 1.

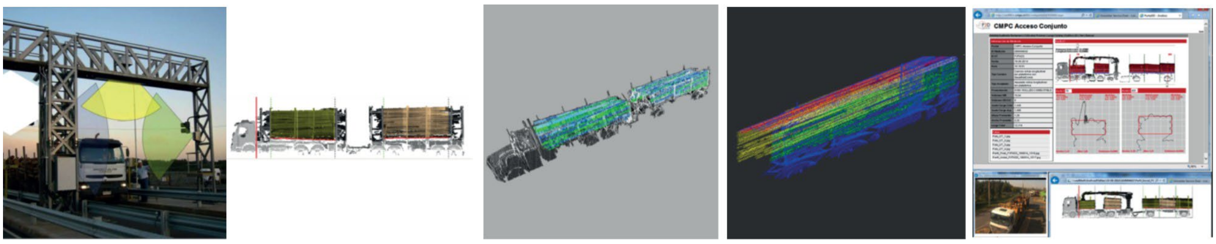

Scanning
Filtering
Biometric characteristics
Scanning
Results

Figure 1. Working phases of a laser scanning system for volumetric measurements of truckloads.

1. Scanning. As the vehicle drives though, the 2D laser scanning system performs up to 1000 scans of the load profile. The system collects and generates a data cloud of millions of points from the logs located in the periphery of each truckload being measured.
2. Filtering. All elements other than the load are filtered out (cabin, protections, vehicle frame).
3. Biometric characteristics. Each log placed on the periphery is scaled: length, diameter, conicity, crook, etc.
4. Solid volume under bark. This data cloud is then processed by a dedicated computer vision algorithm to provide an estimate of the solid volume of logs carried by each truck. Calculated using formulas (multiple regression models).
5. Results. Volumetric calculations, photos and 3D images are stored in a web-based auditing subsystem. The volumetric measurement of a truckload is obtained in less than a minute.

Two Chilean commercial companies that offer standalone laser scanning systems and algorithms, namely WoodTech™ and P3D™, have been identified. WoodTech develops and commercialises measurement solutions for high-value raw materials. These solutions include the Logmeter®, and Bulkmeter® product lines, which use 3D laser scanner technology coupled with state of the art image recognition software to measure the volume and biometric characteristics of log, chip, and coal loads. With customers in Chile, Brazil, and the USA, these companies offer a complete truckload volumetric measurement solution for a purchase price starting at about US$ 500,000. Since March 2018, a first unit has also been operating at Surry Hills chipmill in Tasmania, owned by Forico Pty Limited. The cost of hardware laser components for industrial have dropped substantially in the last years, so it is clear that the major component of this total cost is related to the IP associated with the dedicated volumetric algorithm and software required for operational use.

WoodTech™'s products use either one or three synchronised laser scanners mounted on the top and sides of a measurement portal. Each scanner uses the AR4000-LIR, line scanner, PC104 high-speed interface card and the environmental enclosure. Trucks drive beneath the portal at a constant speed while the system collects profile data from all sides. The software then separates the load from the vehicle, calculates the bulk (gross) and solid volume of the load, and in the case of log loads also measures the characteristics of the load such as lengths, diameters, and quality factors (Figure 2). The whole process takes about two minutes.

In a study conducted with Eucalyptus globulus pulplogs in Chile, the Logmeter® scanning system underestimated the volume of logs on trucks by 0 to 4% in comparison to the manual log measurements. Compared with the manual estimation (measured by a scaler at ground level), the laser system gave 5%, 3%, and 1.5% less volume for small (Avg. mid diameter = 9.2 cm, and Avg. length = 5.61 m), medium (Avg. mid diameter = 13.2 cm, and Avg. length = 5.73 m), and large (Avg. mid diameter = 16.5 cm, and Avg. length = 5.70 m) logs. The correlation,

$r^2 = 99\%$, between the two methods was deemed very good and significant, which indicated a potential that the methods can be calibrated to each other.

Figure 2. Logmeter laser scanning system developed by Woodtech (Source: www.woodtechms.com)

In the case of P3D™ (www.p3d.cl), this company commercialises three products: P3D-Truck®, P3D-Logs®, and P3D-Belt:

- P3D-Truck® is a 3D laser measurement system for wood loads on trucks, like the Logmeter® system developed by WoodTech™. It measures wooden logs of any type, carried by all sorts of trucks with high precision, repeatability and leaving a precise audit trail. Also, it measures chips and biomass. The system determines the gross volume as well as the solid volume under bark (this in conjunction with the P3D-Logs® system). The system can also be combined with truck fleet monitoring systems.

Below it is some of the technical specifications of the P3D-Truck® system:

- Truck types: Semi-trailer trucks, Crib-trailers, Platform trailers, open-top containers
- Load types: Lengthwise, crosswise, mixed / Fixed- and variable-length logs / Chips / Biomass
- Measurement speed: 1 to 5 km/h
- Type of laser sensor used: SICK™ LMS511PRO (100% eye-safe)
- Voltage required: 220 VAC
- Operating temperature: -10ºC to 40ºC system measures as the vehicle positions itself on the weight scale. The whole process takes about two minutes.

- P3D-Logs® is a 3D Laser Volume Measurement System for individual logs placed on conveyor belts. It measures wooden logs of any type when it is installed above the conveyor belt that carries logs from a reception table (or debarker) to the corresponding chipper. P3D-Logs® measures the average diameter, length and solid volume of each log. It is therefore useful for measuring total solid volume of logs processed in a pulp mill, and measuring solid wood volume in single trucks, a substitute for expensive manual measurement methods.

- P3D-Belt® is a 3D Laser System for measuring loose volume of chips/biomass placed on conveyor belts. When installed together with our P3D-Logs® system, it can measure the ratio between solid volume under bark of logs and loose volume of chips, in a continuous (24/7) way. It is therefore useful for measuring the efficiency of a chipper and its variations, measuring total loose volume processed in a pulp mill and measuring the loose volume of biomass processed in a power plant.

Studies carried out with current Woodtech™ customers show that the benefits for a plant can translate into savings of millions of dollars per year. For mills replacing manual measurement, the installation of a Woodtech™ solution means more precise, objective, and significantly faster measurements. The replacement of weight measurement solves the problem of paying for moisture content as well as the corresponding extra transport costs. For all mills, Woodtech™ solutions store the results and images of its measurements, thus providing auditing benefits and reduction in risk of theft or fraud.

In addition, the following benefits associated with their laser scanning measurement system have been reported by P3D™:

- Precise, stable and complete measurement: Average Volume +/- 1% with a standard deviation less than 3% (used in conjunction with our P3D-Logs® system). Repetitive measurements with less than 1% difference. Addition information delivered: diameter, conicity, crook, uneven loading.
- Savings on purchase cost: The high precision produces savings on purchase cost as well as in payments to harvesting teams.
- Reduction of operational costs: Reduction of personnel involved in measurement up to 75% compared to other methods. Reduction of transit time up to 60% (transit time through mill gate can be reduced to 90 seconds, including weight scale and administrative processing. The system measures the truck in less than 60 seconds).
- Complete audit trail reduces conflicts between vendors and purchaser to zero.
- Measurement without exceptions: The system measures wood of any length and load type. 100% of trucks is measured, with no exceptions.
- The client has full control of the measurement process: The system is delivered to be run 100% by the client, with full control of the underlying database and full integration to his ERP system. Results are delivered immediately.
- High operational stability: Uptimes of 99,7% and higher guarantee to the client a 24/365 availability of the system, requiring preventive maintenance of only 8 hours/year. Nevertheless, a 7*24 online remote assistance is available.
- Total assurance of positive results: Client must pay only 30% of the system at delivery of elements to be installed. The rest is paid after certification and beginning of measurement for commercial purposes.

Just recently, an indoor laser scanning system was released by a Swedish company named Mabema AB™ (Figure 3). The technology, called Mabema GPV® (Gauging Pile Volume), is based on an optic 3D laser triangulation with line-lasers as light source for the extremely fast 3D cameras, which take some thousands of images every second on a wood truck that is continuously moving forward at a speed of approximate 1 m/sec (Figure 4). The image captured is carried out by six independent camera/laser systems, strategically placed at different angles around the truck. Three of the systems are looking slightly forward and three slightly backwards. The images from the six cameras are then processed by Mabema AB™'s own developed software for image processing. From the real images a virtual image is created for all areas including top, side and rear/front view whereas in the last case the 3D technique gives information about the position of the log lengthwise and the diameter (Figure 5). It also calculates each logs impact on the total solid wood volume of the pile.

Figure 3. The Mabema GPV® indoor system (Source: www.mabema.se)

Figure 4. The Mabema GPV® laser scanning system for volumetric measurements (Source: www.mabema.se)

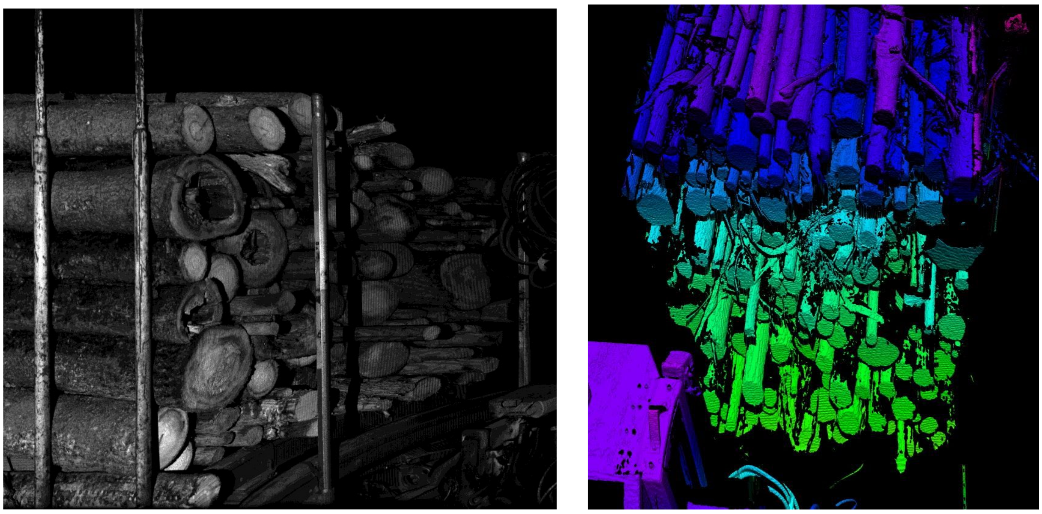
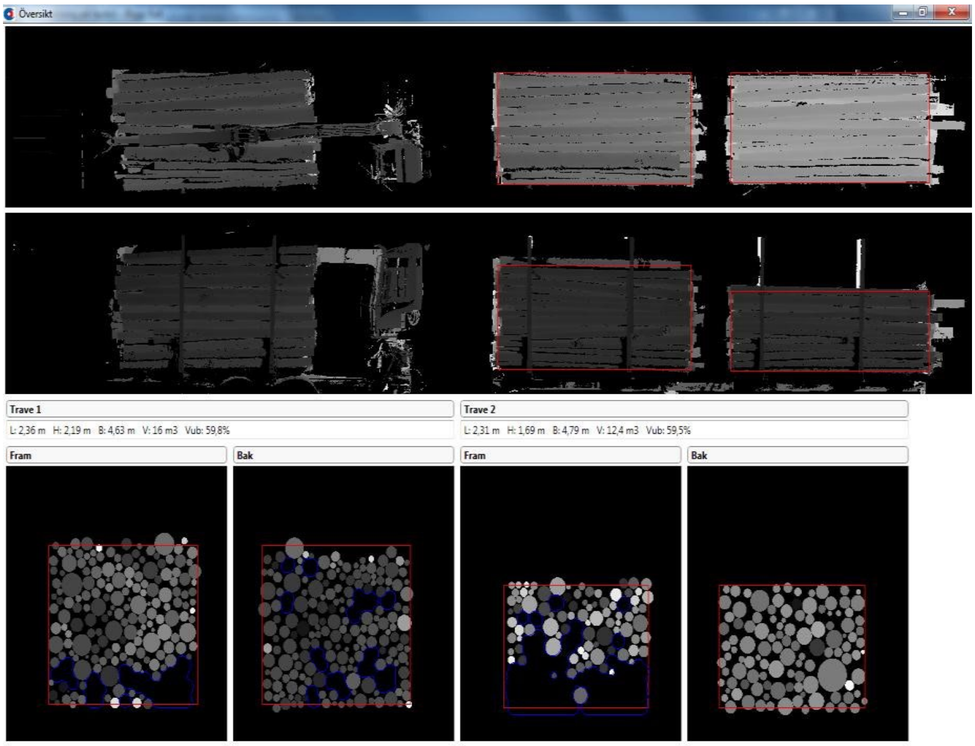


Figure 5. High 3D resolution images from a pile seen in a visualising program. Different colours represent different height data. (Source: www.mabema.se).

Communication between the operator/measuring personnel and the system is a vital part of Mabema AB™'s measuring system. For daily use, an interface has been created which addresses different levels within the wood handling system at the customer sites, from the operator, measuring personnel and technicians to the supplier, transporter and cutters. The interface is usually developed and implemented in conjunction with the customer, to get a system as flexible and easy managed as possible (Figure 6).

Regarding the limitations of the systems, Mabema AB™ claims that their GPV system was developed without any thoughts of limitation when it comes to the type of pile or weather, and that their objective is that all trucks can be measured, regardless of their configuration. However, they indicate that based on experience, that there are some cases of severe conditions that can affect the results negatively. Below is a list of such conditions.

1. Poorly loaded trucks where the logs are all over the place. Short and thick logs packed into the middle of the pile.
2. Piles with bark and branches which creates occlusion at the pile end. Twiggy logs that give a lot of void space between the logs. Difficult to measure log diameter.
3. Large variations in log lengths. This creates occlusion.
4. Lack of space between the piles. Difficult to make an accurate segmentation.
5. Too much snow. This affects the rear pile mainly.
6. Pile loaded to close to the shield plate behind the truck cabin. This can hide a hollow space.



Trave 1: L: 2,36 m H: 2,19 m B: 4,63 m V: 16 m3 Vub: 59,8%

Trave 2: L: 2,31 m H: 1,69 m B: 4,79 m V: 12,4 m3 Vub: 59,5%

Figure 6. Interface of the Mabema GPV® system.

Stereoscopic systems

Stereo camera technology is based on the principle of observing an object from two points of view at the same time. The cameras are set up with a known distance between them and with a calibrated angle between their lines of sight. Because of that, it is possible to measure x-, y- and z- positions of every point in the image with a high degree of precision (Figure 7).

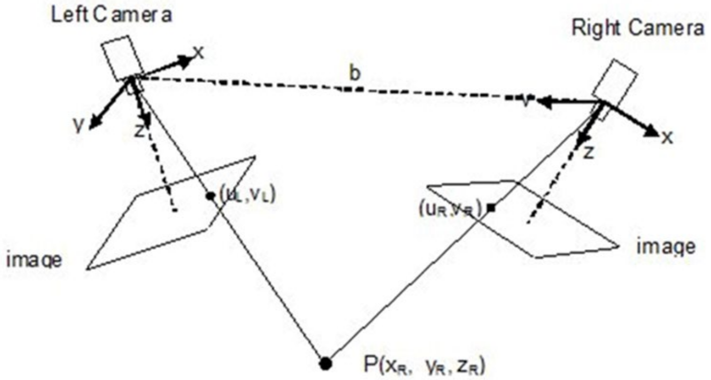


Figure 7. Interface of the Mabema GPV system

The precision of the measurements is determined by the camera resolution. If cameras with 10Mpx resolution are used, i.e. 10 000 000 pixels spread over the surface of the measurable object, there is a large potential for precise measurements. The stereo camera technology can handle a large variation of surfaces and materials and has other properties that make it extraordinarily suitable for the several applications. The ability to measure objects in movement with a high degree of accuracy, as well as the ability to efficiently process large flows of products are among the biggest advantages of applications of this technology.

The Swedish start-up company CIND AB™ has developed a fully automated product for precise 3D measurement of stacks on log trucks named TimSpect® and has delivered a pilot unit in Trätåg, Sweden. The system is based on stereoscopic technology developed by Sweden´s fighter aircraft manufacturer SAAB AB™. The TimSpect® system accurately measures volume as the truck passes through the system, thus allowing for instant and precise volume measurement. Microtec™ introduced this technology to the wood processing industry.

The TimSpect® system uses two pairs of stereo cameras mounted on a gantry through which trucks pass. While the truck passes through, TimSpect®´s stereo cameras and software create a perfect 3D image where the dimensions can be measured (Figure 8). This can be done using manual measurement on the screen or automatically by the system. The system is available both for permanent installation at a site or as a mobile system that can be deployed at any location as required. As the stereo camera system is usually mounted on a gantry, it can be combined with a humidity measurement tool. Moreover, data from a weighing system can be integrated with the volume measurement system to maximise assessment opportunities.

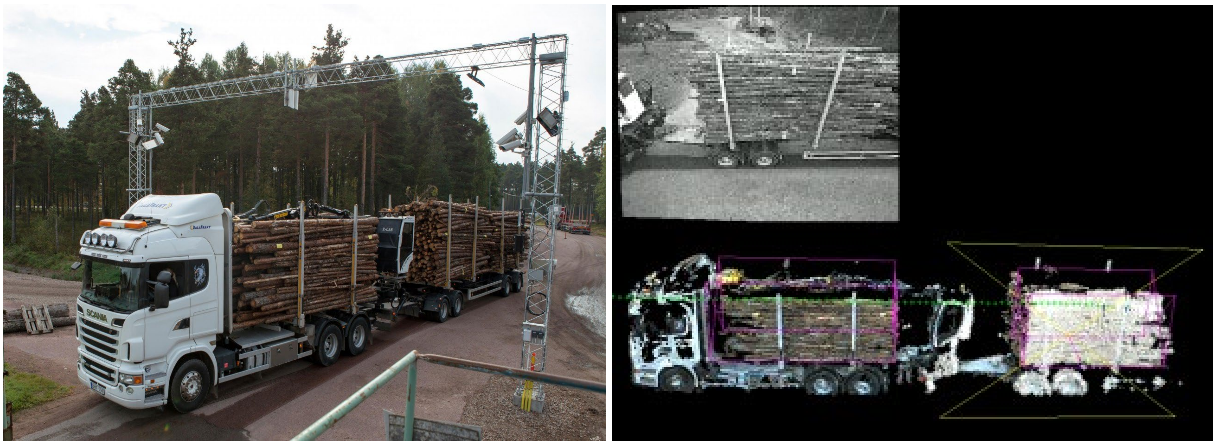


Figure 8. CIND AB™'s automated volumetric measurements of truckloads (Source: www.cind.se)

TimSpect®'s stereo camera system does not use any lasers or other potentially harmful components, which means there are fewer limitations for installing it than for other solutions with similar functionality. The system comprises relatively few hardware components compared to other measurement systems. It consists of two cameras, computers and a few other IT components, as well as lighting (if necessary) and the mechanic components necessary for installation. The system handles most measurements continuously during the real-time flow of goods, something that was a challenge in the past due to the complex calculations necessary to use images as a basis for measuring the flow of goods.

CIND AB™ also highlights other benefits of their TimSpect® system:

- Volume and scaling, as well as inspection of log ends to determine compaction and defects,
- Less demand on vehicle positioning. Scaling takes place when the vehicle drives through the scaling system's gateway. This allows for accurate scaling even if the vehicle is not perfectly aligned through the gateway.
- The system is available in a mobile version for utilisation in more than one terminal or temporary terminals.
- It requires significantly less space and site preparation than other systems. Only 10 metres of width is required which is less than half that of earlier systems.

Based on the same stereo camera technology, CIND AB™ has developed a few other products for the forest industry in Sweden. One of these systems called ChipSpect® automatically measures woodchip volumes on lorry loads. CIND AB™'s system for volume measurement of woodchip lorry loads consists of a couple of stereo cameras that are installed above the vehicle. The system reads the vehicle ID and with the help of an external database of vehicle characteristics automatically determines the volume of woodchips in the current load.

Also, CIND AB™ has developed software for the uniquely exact length and diameter measurements with millimetre precision for every log and its sawing cylinder. The system creates a perfect 3D image of each log as it is being transported to the processing line intake. It takes several pictures of the entire log and combines them to create an image which can be used to determine the log length with millimetre precision. The system determines the form of the log as well, enabling precise measurements of the sawing cylinder.

Finally, CIND AB™ has developed software to automatically detect, delimit and measure the gross volume of individual stacks and piles as well as in full terminals. CIND AB™'s system utilises stereoscopic cameras to construct a complete 3D model of the terminal, which makes volume scaling via a user-interface possible for marked stacks and piles. Depending on the version, the scaling can be done manually with a monitor or fully automatically. By using a complete 3D model of the whole log yard or terminal, the software can automatically detect, delimit and measure the gross volume of individual stacks and piles as well as in log yards and terminals. An operator can then further refine the results by supplementing factors and information per area within the model according to wood type, compaction, etc.

Photogrammetric systems

Multi-view 3D reconstruction is a technology that uses complex algorithms from computer vision to create 3D models of a given target scene from overlapping 2D images obtained from a digital camera (Favalli, 2011). It is based on a technique called Structure from Motion (SfM), which is a photogrammetric range imaging technique for estimating three-dimensional structures from two-dimensional image sequences that may be coupled with local motion signals (Figure 9). It is studied in the fields of computer vision and visual perception. It is an inexpensive, effective, flexible, and user-friendly photogrammetric technique for obtaining high-resolution datasets of complex topographies at different scales. The requirement for 3D modelling within various industries such as forestry, surveying, civil engineering and archaeology has fronted the advancement in photogrammetry techniques and 3D modelling software to a point where now open-source and commercial software solutions can be used by non-vision experts.

Photogrammetry has been used in geotechnical engineering since the early 1970s. Wickens and Barton (1971) explored the use of photogrammetric measurements to estimate the stability of slopes in open cut mines and to identify the rock face characteristics such as orientation, spacing and persistence of the rock joints. With the recent advances in computer vision (Hartley and Zisserman, 2003) there is a need to show that these new technologies can be applied to other industries such as forestry. Modern range-based techniques, such as terrestrial laser scanning, have also become more popular over recent years. Although these techniques are more powerful and accurate in theory, image-based techniques can be more cost-effective, convenient and practical.

The SfM techniques have improved the quality of 3D data that can be derived from overlapping imagery by incorporating advancements in soft-copy triangulation and image-based terrain extraction algorithms (Westoby et al., 2012). Furthermore, SfM can accurately reconstruct scene geometry using high-resolution overlapping imagery obtained with single lens reflex (SLR) cameras and consumer point-and-shoot cameras, rather than relying on stereoscopic cameras, thus enhancing the accessibility and accuracy of 3D photogrammetric modelling for an array of uses.

SfM techniques utilise the basic principles of stereoscopic photogrammetry, which is the science of obtaining reliable information about physical objects, the environment and terrain through processes of recording, measuring, and interpreting photographs or other images. However, the fundamental advantage of SfM is that the geometry of the photographed scene, camera positions, and orientation are evaluated without the need for a priori specification of targets with known 3D positions (Snavely et al., 2008). Rather, SfM photogrammetry determines these parameters simultaneously with a highly redundant and iterative bundle adjustment procedure, which is based on a dataset of invariant features extracted from multiple overlapping images (Westoby et al., 2012). These features are tracked from image to image, enabling initial estimates of camera position and object coordinates which are then refined iteratively using non-linear least squares minimisation (Fonstad et al., 2013). This process produces a point cloud of identifiable features present in the input photographs. Once georeferenced, this point cloud can be used to generate an array of digital elevation metrics to quantify 3D characteristics. Automating the process from identification of control points to the 3D reconstruction of scene geometry makes SfM substantially more practical and cost-effective than traditional photogrammetric methodologies. Multiple studies have validated the accuracy of SfM techniques for high-resolution 3D topographic reconstruction and analysis, and in some cases found SfM to be highly comparable to substantially more expensive LIDAR techniques (Harwin & Lucieer, 2012).

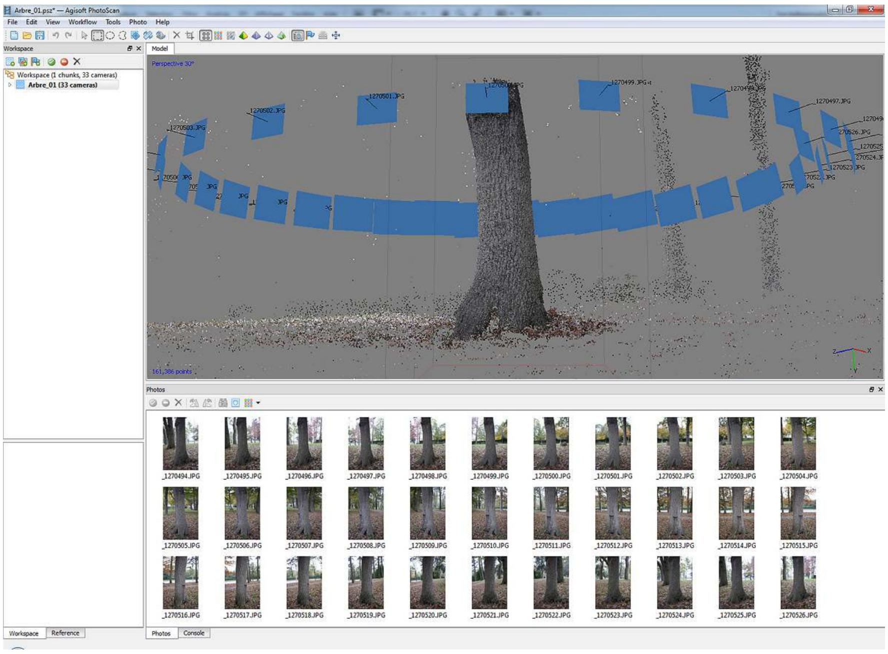


Figure 9. Multi-view 3D reconstruction of a tree based on the SfM technique

In the case of forestry, SfM and remote sensing have been mainly employed to complementing existing ground-based techniques, providing spatially representative characteristics of investigated forest stands more efficiently. Data captured over varying spatial, spectral, and temporal scales has been shown to contain information, which can be used to measure and monitor various aspects of a complex forest structure (Zellweger et al. 2013). Advances in the acquisition of this information have led to high spatial resolution three-dimensional (3D) remote sensing becoming an important tool in forest modelling (St-Onge et al. 2013).

Small-size unmanned aerial vehicles (mini-UAVs of less than 5 kg) represent a low-cost remote sensing alternative to airborne and satellite platforms that, when equipped with sensors, can produce cost-effective data at local scales (e.g., for areas the size of traditional forest plots up to areas of several km^2) with an unrivalled combination of spatial and temporal resolution. Equipping mini-UAVs with sensors capable of detecting 3D structure has led to the systems being increasingly used to provide an understanding of the structure and variability of forests (Figure 10).

Figure 10. Mini-UAV and spatial data collected from photographs

Comparisons between Airborne LiDAR data collected from manned aircraft and point clouds produced from UAV-collected photographs (Lisein et al. 2013), but also data captured solely from manned aircraft (Wallace et al. 2014), have shown that differences occur at all stages of the data processing workflow, i.e., from data collection through the generation of metrics to the assessment of object structure. Notably, it has been shown that imagery can capture spectral information that in some cases produces a more detailed representation of the upper canopy (Dandois and Ellis 2013). Imaging technology, however, does not provide the same level of penetration into the canopy as laser scanning, and therefore cannot deliver the same level of information on vertical stratification of vegetation layers and the terrain. Furthermore, because ground terrain needs to be visible from multiple locations to estimate its 3D location, several studies have highlighted that the accurate generation of canopy height information from SfM often requires the use of a digital terrain model (DTM) supplied from an external source (Lisein et al. 2013).

Volumetric measurement of truckloads through multi-view photogrammetry and 3D image processing software: Results from a research trial

This section of the report presents the results of the research trial conducted in 2017. The general objective of the study was to test the ability of multi-view photogrammetry and use of commercial 3D image processing software for automated volumetric measurement of trucks loads. Also, the study aimed to predict solid volume from the gross volume estimated with multi-view photogrammetry and use of commercial 3D image processing software.

Methods

Data collection with UAV

Data from 10 Semitrailer truckloads delivering Eucalyptus nitens logs to the Surrey Hills chip mill (located in Northern Tasmania and owned by Forico Pty Limited) were collected with an Unmanned Aerial Vehicle (UAV). The UAV corresponded to a drone Phantom 4 developed by the company DJI™ (Figure 11). The Phantom 4 is a 1.38 kg drone, with a maximum speed of 20 m/s and a maximum flight time of 28 minutes. It comes with a GPS/GLONASS system which allows geotagging of the pictures that are taken during the flight. The specifications of the built-in camera are shown in Table 1.

Figure 11. UAV (Phantom 4) and camera used to collect the photographs from Semitrailers

Flights around logging trucks were performed at a height that ranged between 12.4 and 18.6 metres. For this purpose, a “Point of Interest” flight mode was selected, where a specific building, location or object (truckload in this case) was set as the point of interest, and the UAV continuously circled it while photos were recorded every 3 seconds (Figure 12).

Table 1. Technical specifications of the camera mounted on the Phantom 4.

Specification	**Value**
Camera model	FC330
Effective pixels	12.4 M
Sensor	1/1.3” (6.17 x 4.55 mm) CMOS
Resolution	4000 x 3000
Focal length	3.61 mm
Pixel size	1.56 x 1.56
Video recording modes	FHD: 1920×1080 24 / 25 / 30 / 48 / 50 / 60 / 120p HD: 1280×720 24 / 25 / 30 / 48 / 50 / 60p
Format photos	JPEG, DNG (raw)
Format videos	MP4, MOV

Figure 12. Camera locations above logging trucks during data capture with UAV

Processing images of each truckload with 3D reconstruction software

Between 30 and 66 photos (average 48 photos) were collected from the 10 truckloads. Processing of the images collected with the drone was performed with the software AgiSoft PhotoScan™ version 1.3.2. PhotoScan is an advanced image-based 3D modelling solution for creating professional quality 3D content from still images. Based on the latest multi-view 3D reconstruction technology, it operates on arbitrary images and is efficient in both controlled and uncontrolled conditions. The photos can be taken from any position, provided that an object to be reconstructed is visible on at least two photos. Both image alignment and 3D model reconstruction are fully automated. Supported input formats: JPEG, TIFF, PNG, BMP, JPEG Multi-Picture Format (MPO). Supported output formats: Wavefront OBJ, 3DS Max, PLY, VRML, COLLADA, Universal 3D, PDF (Agisoft, 2018a).

The state-of-the-art technology developed by Agisoft™ allows for very fast processing (typically within 30 min), providing at the same time highly accurate results (up to 3 cm for aerial, and up to 1 mm for close-range photography) (Agisoft, 2018a). The package has a linear project-based workflow that is intuitive and can be easily mastered even by a non-specialist, while professional photogrammetrists have complete control over the results accuracy, with detailed report being generated at the end of processing. The workflow includes the following steps:

1. Taking photos from each truckload with the UAV.

2. Aligning photographs and generating sparse point cloud. Once photos are loaded into PhotoScan™, they need to be aligned. At this stage, the software finds the camera position and orientation for each photo and builds a sparse point cloud model. The density of this point cloud for the 10 truckloads ranged between 24,128 and 35,596 points. The alignment process has several parameter controls. There are three different accuracy settings for the alignment process: low, medium and high. For this study, High accuracy was selected, which requires much more processing time but camera position estimates obtained are the most accurate (Agisoft, 2018b).

3. Generating dense point cloud. After alignment and optimisation, which included the determination of exterior and interior camera parameters, were complete, the dense multi-view 3D reconstruction algorithm was executed. Based on the estimated camera positions the program calculates depth information for each camera to be combined into a single dense point cloud (Agisoft, 2018b). PhotoScan™ tends to produce extra dense point clouds, which are of almost the same density, if not denser, as LiDAR point clouds. When exporting a dense point cloud, Photoscan offers the possibility to specify the quality. For this study, High quality was selected. This resulted in dense point clouds with point cloud densities ranging between 607,000 and 1,374,000 points for the 10 truckloads.

4. Building mesh (3D polygonal model). A mesh (3D model) is created from the dense point cloud. PhotoScan™ supports several reconstruction methods and settings to produce optimal reconstructions for a given data set. In the case of this study, “Arbitrary surface” was selected, which it doesn't make any assumptions on the type of the object being modelled, which comes at the cost of higher memory consumption (Agisoft, 2018b). The use of a dense cloud as a source data results in longer processing time but will generate high-quality output. The number of faces and vertices in the 3D models ranged between 180,000 and 274,400, and between 90,500 and 138,000, respectively.

5. Generating texture. In a next step, pixel data from the photographs are used to generate a 3D model texture. Again, there are different texture mapping modes. In the case of this study, a Generic mapping mode was selected, which makes no assumptions regarding the type of the scene to be processed are made; thus, the program tries to create as uniform texture as possible (Agisoft, 2018b).

6. Building tiled model. This is an optional step and allows for responsive visualisation of large area 3D models in high resolution. An example of a tiled model has been exported to Sketchfab™ for visualisation (Figure 13) on the following link: https://sketchfab.com/macuna. The tiled model is build based on dense point cloud data. Hierarchical tiles are textured from the source imagery.

Photorealistic, highly detailed 3D models, classified dense point clouds, fine resolution DEMs generated with the software can be used in wide range of applications, from visual effects industry to engineering projects. Also, high accuracy of polygonal models and Digital Surface models reconstructed with the software guarantees precise area and volume measurements. This feature makes it possible to use this technology and software for volumetric measurements of truckloads.

Figure 13. 3D model uploaded in Sketchfab™ for high-resolution visualisation

Calculating gross volume from a 3D model

The 3D textured model (file of extension *.obj) was imported in the software Autodesk Remake™ where the model was extruded to facilitate the calculation of the gross volume by the algorithm included in the tool. The mesh report provides the number of faces and vertices, surface area and volume of the 3D model (Figure 14).

Measuring the truckloads for solid volume

Each truckload was physically measured on the ground for actual solid wood volume. For that purpose, 1,605 fully debarked logs were measured for mid-diameter and total length. Mid-diameter was measured to the nearest millimetre with a calliper. In addition to mid-diameter, the length of each log was measured to the nearest 0.1 m with a tape. Both mid-diameter and length data was recorded with a Windows tablet for further processing (Figure 15).

Vertices: 456,737
Faces: 788,192
Surface area: 129 m^2
Volume: 45.403 m^3

Figure 14. 3D model and mesh report provided by Autodesk Remake™

The solid volume of the logs was calculated using Huber's equation, which uses mid-diameter and length as inputs. Huber's volume equation is as follows:

$$Sv = \frac{1}{1{,}000{,}000} * \pi * \frac{Dm^2}{4} * L$$

where:
Sv = Solid volume (m^3), Dm = Mid-diameter (mm), L = Log length (m)

Figure 15. Log measurements and recording at the trial site

Estimating solid volume from gross volume

To predict the solid volume of each truckload, a linear regression model between the explanatory variable “Gross volume” (from photographs and 3D reconstruction) and the response variable “solid volume” (from measurement on the ground) was developed. The linear regression model had the following form:

$$Solid\ volume\ [m^3] = a + b * Gross\ volume\ [m^3]$$

Results

Summary of the flights around logging trucks and processing of the images

Table 2 shows a summary of the flights performed around the 10 logging trucks, including aligned images, flying altitude, ground resolution and coverage area. Ground resolution is high given the short distance between the camera allocation and then trucks. It is clear that ground resolution increases at lower flight altitudes. For example, at a flight altitude of 12.4 m (Truck 6), the ground resolution is 4.6 mm/pix, while at a flight altitude of 18.6 m (Truck 1), the ground resolution is 6.2 mm/pix. Figure 16 shows an image of the sparse point cloud generated with Agisoft PhotoScan™. On average, around 29,000 points were generated from the photos of each truckload. Matching time ranged between 1.6 and 10.1 minutes (average = 4.5 minutes), while alignment time ranged between 0.16 and 0.5 minutes (average = 0.2 minutes).

Table 2. Summary of the flight performed around the 10 logging trucks

	Truckload									
	1	2	3	4	5	6	7	8	9	10
# Aligned images	37	37	36	51	66	46	54	55	64	30
Flying altitude (m)	18.6	13.2	14.8	17.3	14.1	12.4	12.8	15.0	15.2	16.4
Ground resolution (mm/pix)	6.2	4.5	5.4	5.6	5.4	4.6	4.9	5.3	5.2	5.5
Coverage area (m^2)	40.9	54.6	30.1	29.1	28.8	31.0	36.8	31.6	29.2	65.9

An image of the 3D model (mesh for whole truck and load) is shown in Figure 17. On average, around 214,000 faces and 107,660 vertices were generated for each truckload. Processing time ranged between 0.5 and 1.2 minutes (average = 0.9 minutes).

Finally, Figure 18 shows the tiled model generated from the dense cloud with Agisoft PhotoScan™. The tile size was 256 pixels. Processing time ranged between 1.4 and 2.5 minutes (average = 2.1 minutes).

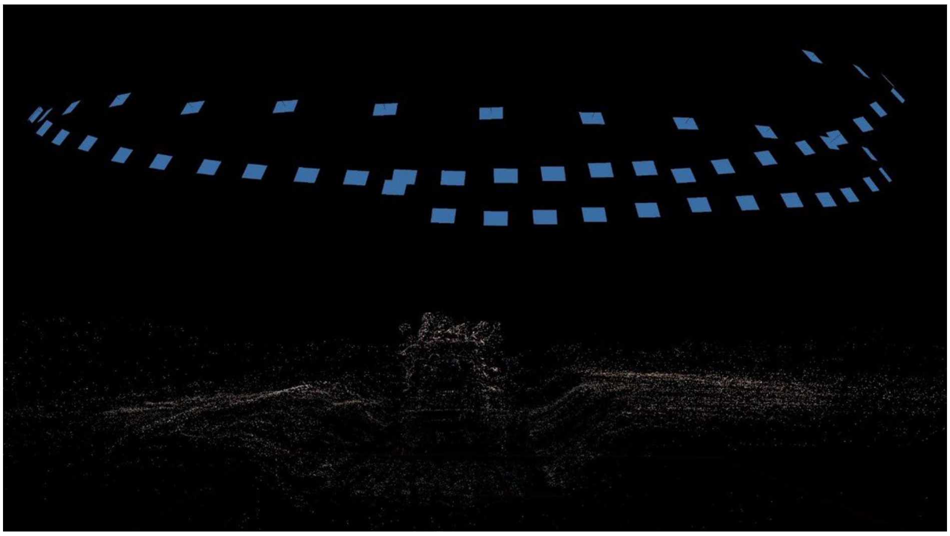


Figure 16. Sparse point cloud generated with Agisoft PhotoScan™

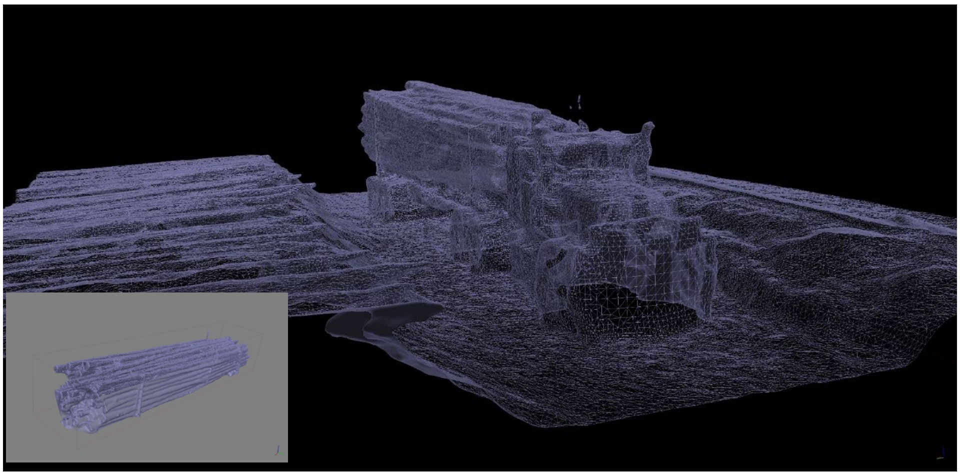


Figure 17. 3D model (mesh) generated with Agisoft PhotoScan™

Figure 18. Tile model generated with Agisoft PhotoScan™

Processing time for the 3D reconstruction of the truckloads

Total processing times (including processing to generate the titled model) ranged between 10.1 and 52.2 minutes (average = 30.9 minutes). The variation in Total time is explained by the number of images to generate the 3D model as well as the average flight altitude when capturing the photographs. Processing time increases when more images are used to generate the models and when these photographs are captured at a lower altitude. The regression model is as follows:

$$Processing\ time\ [min] = 36.9 + (1.01 * \#Images) - (3.6 * Altitude\ [m]), \qquad r^2 = 0.86$$

A regression model between actual and predictive processing time is shown in Figure 19.

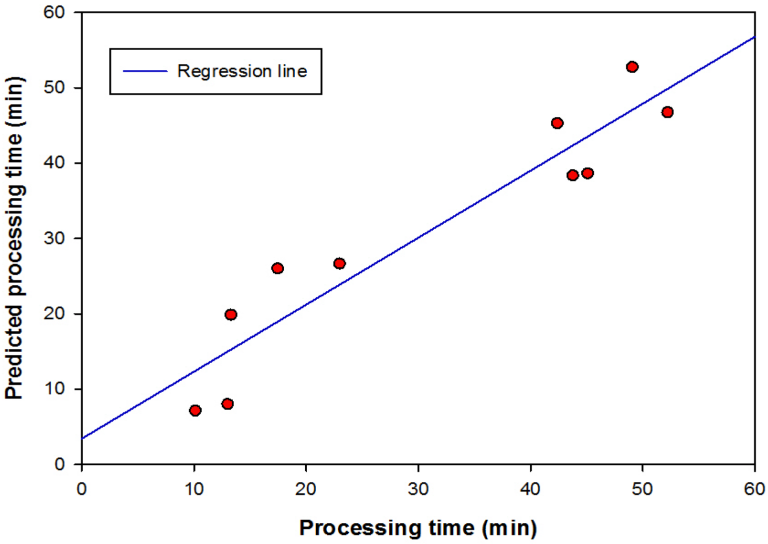


Figure 19. Regression model between actual and predicted processing time

Summary statistics of the truckloads

Table 3 presents a summary of the statistics of the logs being transported by the ten trucks included in the study (1,605 logs). These include the mid-diameter measured in the centre of the logs, total length, and solid volume calculated with the Huber equation.

Table 4 shows summary statistics for Gross Vehicle Mass (GVM), tare, net payload, solid volume, gross volume calculated from 3D models, and solid-to-gross ratio by truck.

There was a big difference in GVM (8.8 tonnes) and net payload (7.5 tonnes) between the lightest and the heaviest trucks, although their difference in tare was only 3.1 tonnes. The inclusion of these two trucks did not affect the average GVM, tare, and net payload which were around 45.8, 15.8, and 30.0 tonnes, respectively, for the ten trucks included in the study.

Table 3. Summary of statistics for the long logs measured in the study

	Mid-diameter (mm)	Log length (m)	Solid volume (m^3)
Min.	80.0	2.0	0.01
Max.	361.0	13.3	1.11
Mean	163.1	9.6	0.23
Median	158.0	10.9	0.19
Std. Dev.	47.2	2.4	0.16

Regarding solid volume, there was a difference of 5.4 m^3 between the lightest and the heaviest trucks. The average solid volume was 28.5 m^3 for the ten trucks, which is lower than the 30.2 m^3 calculated in a previous study from 54 truckloads. This difference is explained in part by the date of each trial (end of summer in the previous trial and mid-winter in the case of the present study), as well as the volume equation used (Smalian in the previous trial and Huber in the case of the present study). Also, there was a high correlation between net payload and solid volume (Pearson coefficient of correlation = 0.87). This high correlation can be explained in part by the fact that all the loads were moved from the forest to the chip mill immediately after harvesting, and consisting of logs with similar moisture content and basic density.

Regarding gross volume, the gap between the lightest and the heaviest trucks was 6.7 tonnes, which was bigger than the gap in solid volume, and with greater variation among the trucks. The average gross volume was 44.8 m^3 for the ten trucks, which is lower than the 47.9 m^3 calculated in a previous study from 54 truckloads. This difference is explained in part by the method being used to determine the gross volume (pictures taken from both sides of the trucks in the previous trial and multi-view photogrammetry and 3D reconstruction in the present study). The average solid-to-gross ratio in the present study for ten trucks (0.64) was very close to the one calculated in the previous trial for 54 trucks (0.63). The difference between the maximum and minimum values (0.05) and the standard variation (0.02) was smaller in the present study than in the previous study.

Table 4. Summary statistics for the 10 truckloads included in the study

Truck	GVM (tonnes)	Tare (tonnes)	Net payload (tonnes)	Solid volume (m^3)	Gross volume (m^3)
1	45.90	14.95	30.95	29.04	43.73
2	45.55	15.35	30.20	28.52	45.92
3	50.35	16.10	34.25	31.64	47.56
4	41.55	14.75	26.80	26.20	40.85
5	46.00	15.65	30.35	29.09	45.40
6	46.00	15.70	30.30	29.13	45.15
7	45.35	14.95	30.40	28.86	45.97
8	46.10	15.15	30.95	28.73	45.95
9	46.50	17.85	28.60	27.15	43.13
10	45.35	15.50	29.85	28.80	44.83
Min	41.55	14.75	26.80	26.20	40.85
Max	50.35	17.85	34.25	31.64	47.56
Average	45.88	15.78	30.09	28.54	44.85
Std. dev.	2.00	1.05	1.87	1.46	1.87

Estimating solid volume from gross volume

A good prediction of solid volume from gross volume was achieved with a regression model that combined the data of the ten truckloads (Figure 20). The regression equation obtained was as follows:

$$Solid\ volume\ [m^3] = -0.617 + (0.654 * Gross\ volume\ [m^3]), \qquad r^2 = 0.76$$

A relatively high correlation was observed between gross and solid volume. This even though the model was only developed from 10 truckloads. This is also corroborated by the results presented in Table 5, which shows a summary by truck of the gross and solid volume, predicted solid volume with the above regression model, and the errors (deviations) between the actual and the predicted solid volume. Positive deviations mean that the actual solid volume was bigger than the predicted solid volume (the model underestimates solid volume), while negative deviations mean that the actual solid volume was smaller than the predicted solid volume (the model overestimates solid volume). As shown in Table 6, the deviation for the 10 trucks ranged between -0.9 and 1.2 m^3, with an average value of 0.5 m^3. However, the absolute deviation only ranged between 0.0 and 1.2 m^3, with the same average value of 0.5 m^3. These values represent a maximum absolute deviation of 3.5%, with an average value of only 1.7% for the 10 trucks.

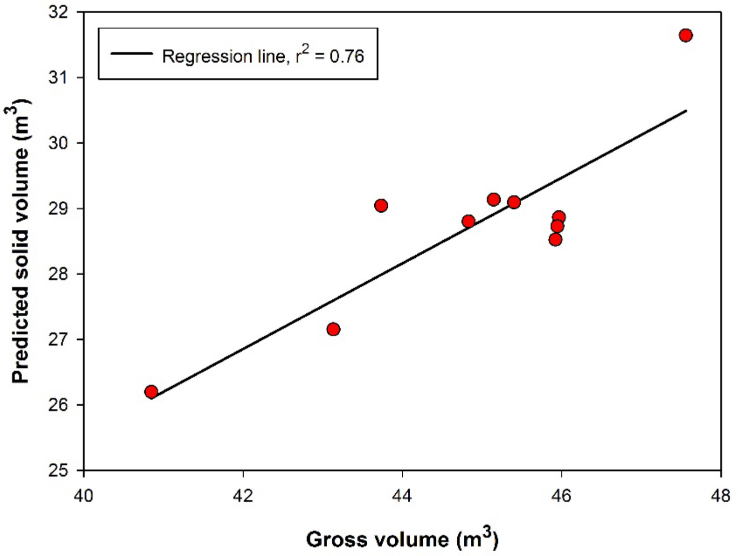


Figure 20. Regression model between gross and predicted solid volume of logs on trucks

Table 5. Summary of gross and solid volume, and errors by truck

	Truck									
	1	2	3	4	5	6	7	8	9	10
Gross Volume* (m^3)	43.7	45.9	47.6	40.8	45.4	45.1	46.0	45.9	43.1	44.8
Actual solid volume (m^3)	29.0	28.5	31.6	26.2	29.1	29.1	28.9	28.7	27.2	28.8
Predicted solid volume (m^3)	28.0	29.4	30.5	26.1	29.1	28.9	29.4	29.4	27.6	28.7
Deviation (m^3)	1.05	-0.90	1.15	0.10	0.01	0.22	-0.58	-0.71	-0.44	0.09
Deviation (%)	3.45	-3.16	3.48	0.38	0.00	0.69	-1.73	-2.44	-1.47	0.35

* Calculated with photogrammetry and 3D reconstruction

The levels of accuracy obtained with photogrammetry and 3D reconstruction are quite similar to the ones reported in previous studies with laser scanning systems. For example, in the study conducted by Nylinder et al. (2010), deviations between gross volume measured manually and estimated with laser scanning systems ranged between 1.7% and -4.5% for E. globulus pulplogs.

These results confirm that photogrammetric and 3D reconstruction methods are a good option to provide accurate gross volume estimates. AFORA will continue exploring the use photogrammetric methods that enable the generation of 3D profiles from several digital pictures taken around an object, in this case, loads of logs on trucks. Commercial software and algorithms to process the photos and generate the 3D profiles are progressing quite rapidly, and the approach has demonstrated to be as accurate as the one based on laser scanning systems, but a more affordable option.

Table 6. Summary of gross and solid volume, and errors for the 10 trucks in the study

	Min	Max	Average	Std. deviation
Gross Volume* (m^3)	40.8	47.6	44.8	1.9
Actual solid volume (m^3)	26.2	31.6	28.7	1.4
Predicted solid volume (m^3)	26.1	30.5	28.7	1.2
Deviation (m^3)	-0.9	1.2	0.5	0.4
Absolute Deviation (m^3)	0.0	1.2	0.5	0.4
Absolute Deviation (%)	0.0	3.5	1.7	1.4

* Calculated with photogrammetry and 3D reconstruction

Conclusions and Recommendations

This report provides an extensive literature review of laser, stereoscopic and photogrammetric systems for truckload volumetric measurements. It also reports the results of a study on the use of multi-view structure from motion (SfM) photogrammetry and commercial 3D image processing software that were tested as an innovative and alternative method for automated volumetric measurement of truckloads.

Accurate and efficient volumetric measurements systems are considered to be essential to business in the forest industry. Timely and accurate provision of volumetric measurements is a key component along the supply chain, among others, for forest inventory purposes, forest operations planning, allocation of logs from stands to markets, efficient logistics and stock control management, and when used as part of a commercial mechanism for payment of logging and haulage operations.

Automated systems for volumetric measurements of truckloads are well established by the forest industry in other regions of the world such as South America and Scandinavia. Practically none of these systems have being adopted or implemented in Australasia, and currently nearly all logging and haulage transactions in Australia are paid on a green-weight basis. Weight, however, is significantly impacted by several variables, particularly season of the year. Timber can get wet and therefore, heavier, impacting transport costs on a per cubic metre basis.

From all the sensor technologies for volumetric measurements presented in this review, laser scanning is perhaps the most mature and proved technology, and potentially suitable for Australia. Just recently, Forico Pty Limited has implemented the Logmeter laser scanning systems at the Surry Hills chipmill in Northern Tasmania, being the first unit of this type operating in Australasia. Recently, stereoscopic systems have been also become commercially available in Sweden, but nothing is known about their cost and accuracy. In principle, this technology has the same capabilities as laser scanning units, providing volumetric measurements of truckloads in near real-time.

As reported in this document, photogrammetry and commercial 3D image processing software is also a promising technology and an alternative method for more expensive automated volumetric measurement of truckloads. The levels of accuracy obtained with multi-view SfM photogrammetry and 3D reconstruction obtained in the study presented in this report were comparable to those reported in previous studies with laser scanning systems for truckloads with similar logs and species. The deviations between actual and predicted solid volume of logs on trucks ranged between -3.2% and 3.5%, with an average deviation -0.05%. In absolute terms, the average deviation was only 0.5 m^3 or 1.7%. Despite the above results, the implementation of this technology in operating conditions still requires that photo collection and processing times are reduced considerably. To our best knowledge, there are no commercial providers of volumetric measurement of truckloads using this technology.

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Comparison of Ship Loading Rates: Logs in Containers vs Bulk Cargo

Prepared for

Forest & Wood Products Australia

by

Glen Murphy

Executive summary

Internationally most logs are shipped and exported in bulk, or loose, form. Only a relatively small proportion is exported in containers. The opportunity to backload logs, in what would have been empty containers otherwise, is attractive to some shipping companies and competitive shipping prices can be offered.

It has been estimated that up to 60% of the cost of sales for logs exported to Asia is in marine freight and port costs. Ship loading rates effect total voyage times, port costs and potentially demurrage fees.

Using a mix of publicly available data, recent container handling productivity studies and information provided by marine port and forest industry experts estimates were made of ship loading rates for logs in containers versus bulk cargo logs.

Load rates were estimated to be six time faster for logs in containers (835 JAS m^3 per crane per hour) versus for bulk cargo log loading (140 JAS m^3 per crane per hour).

The economic trade-offs between the potential cost savings associated with faster ship loading times and the additional costs associated with placing logs into the containers prior to ship loading will be the subject of a separate report. The load rate information included in this report will form part of the economic analysis.

Table of Contents

Executive Summary i
Introduction 1
Importance of Port and Shipping Activities in the Supply Chain 1
Study Methods 4
Load Rates 5
    Bulk Cargo 5
    Container 6
System Comparisons 7
Discussion and Conclusions 9
References
Executive summary i
Introduction 1
    Study Methods 4
References 10

Introduction

In 2016 global industrial roundwood production amounted to 1874 million m^3 (FAO 2017). Approximately 7% of this production (132 million m^3) was exported in roundwood form. Australia was the sixth largest log exporter (3.9 million m^3).

Although no exact numbers are available most logs are shipped and exported in bulk, or loose, form. A relatively small proportion is exported in containers.

Loading logs into containers, and unloading them again on arrival at their destination, requires some effort and cost (Murphy et al. 2018). Nevertheless, logs are currently being exported in containers to Asia from Australia as well as from other parts of the world such as Africa, Europe, Canada, USA, and New Zealand.

Why ship logs in containers? Regional trade imbalances mean that many shipping companies are faced with repositioning empty containers from container surplus to container shortage locations. For example, one of the world's largest shipping companies is faced with repositioning 900,000 empty TEU's (20-foot equivalent container units) annually to cover uneven regional demand for containers. Repositioning empty containers is this shipping company's largest operational cost after ship fuel (Epstein et al. 2012).

The opportunity to backload logs, in what would have been empty containers otherwise, is attractive to some shipping companies and competitive shipping prices can be offered. The other big benefit for both exporters and importers is that small lots of just a few hundred cubic meters can be delivered and the exporter isn't restricted to the main ports that can handle bulk logs. This opens up the market to niche buyers and sellers serviced by more ports (Weblin 2008). Gains in forest gate returns of up to $10 per JAS m^3 have been reported.

The opportunity to backload in containers, what has traditionally been bulk cargo, extends to other products as well. For example, analysts estimate that 12 to 15% of Australia's grain exports are now shipped in containers to Asia[1].

This publication briefly looks at the relative importance of port activities in terms of cost in moving logs from ports to international customers. It then compares ship load rates for logs in containers versus logs in bulk form and comments on some potential factors for increasing load rates.

Importance of Port and Shipping Activities in the Supply Chain

In a recent review of shipping and handling costs for Australia's wood product exports ABARES (2016) concluded that "estimating shipping and port handling costs for Australian ports is problematic". Cost data is often commercially sensitive and not publicly available.

UNCTAD (2017) reports that maritime freight and insurance costs globally were equivalent to about 15% of the value of imports in 2016. There is large variation in this percentage due to such things as transport distance, volume of trade, daily shipping rates, shipping policy (e.g. "slow steaming"), and value of the goods (compare for example the value of a 1 tonne car versus 1 tonne of logs).

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[1] Source: https://www.reuters.com/article/agri-container-idUSL5N0LF3MZ20140214

Christie (1995) noted that shipping costs were approximately 50% and port costs were approximately 10% of the cost of sale of bulk logs from New Zealand to Asian markets (Figure 1). Activities included in cost of sales were logging and loading, cartage, port costs, and shipping costs. Ship charter rates for Handysize vessels (typically used for bulk log exports from Australia and New Zealand) in 1995 were about US$9000 per day, which are similar to what they were for container ships in mid-2018 (Figure 2). Fifteen years later, in 2010, shipping costs were still estimated to be approximately 50% of the costs of sale of bulk logs (PFOlsen, 2010).

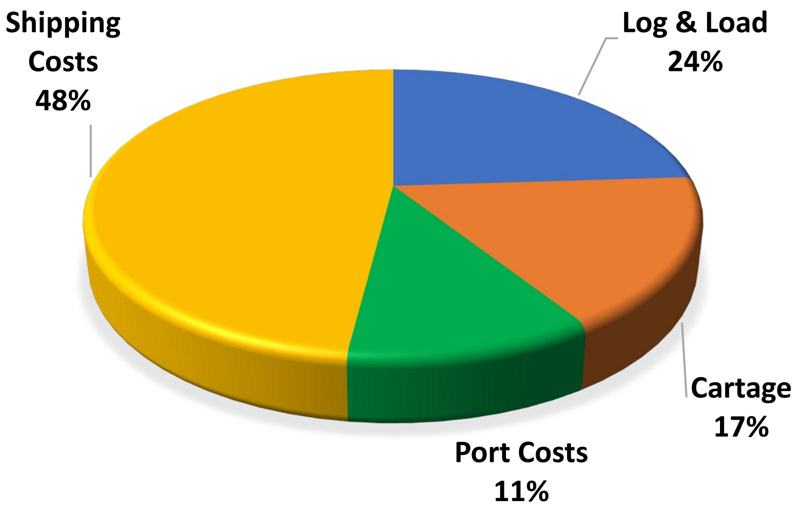

Figure 1. Cost of sales for export A-grade logs delivered to Asian markets from New Zealand (Adapted from Christie (1995)).

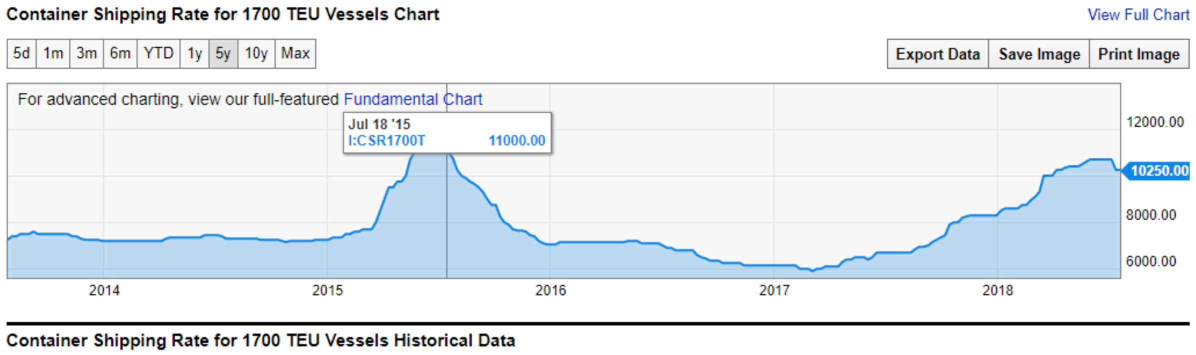
For advanced charting, view our full-featured Fundamental Chart

Figure 2. Daily container shipping rates (US$) for 1700 TEU (twenty-foot equivalent units) vessels. Source: https://ycharts.com/indicators/container_shipping_rate_for_1700_teu_vessels accessed 29 July 2018.

When a ship is in port three main sources of costs are incurred: the daily ship charter costs (less costs of bunker fuel not being used while the ship is idle[2]), any demurrage costs, and the port costs. As shown in Figure 2 charter rates have varied between US$6000 and US$11000 per day over the past three years. Demurrage is the cost a charterer of a ship incurs if the ship

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[2] Bunker fuel prices account for 70% of the costs of operating a dry bulk vessel. https://www.spglobal.com/platts/en/market-insights/latest-news/shipping/101714-falling-bunker-fuel-prices-pull-down-dry-bulk-and-tanker-freight-rates

exceeds the allotted time for the voyage, usually due to in-port delays. It is a negotiated rate and can be one to two times the daily ship charter rate. Port costs are comprised of many services (see for example the schedule of port charges for the Port of Portland in Victoria http://www.portofportland.com.au/images/stories/port_charges/port_charges_fy19-1st_qtr-website.pdf accessed 29 July 2018).

In 2007 the South Australian government undertook a review of port charges per visit for dry bulk vessels (includes wood chip vessels and bulk log vessels) and container vessels (Figure 3 and 4). Charges per visit ranged between A$55 and A$175 thousand (A$70 to A$220 thousand after an adjustment for inflation). The great majority of the charges are fixed (e.g. pilotage) or cargo related (e.g. $ per tonne or $ per container). Only a small portion of the port costs were time related ($ per day for berth hire). Per diem berth hire costs averaged 6.5% of total port costs for dry bulk vessels (range 1% to 14%) and 4.8% for container vessels (range 1% to 10%).

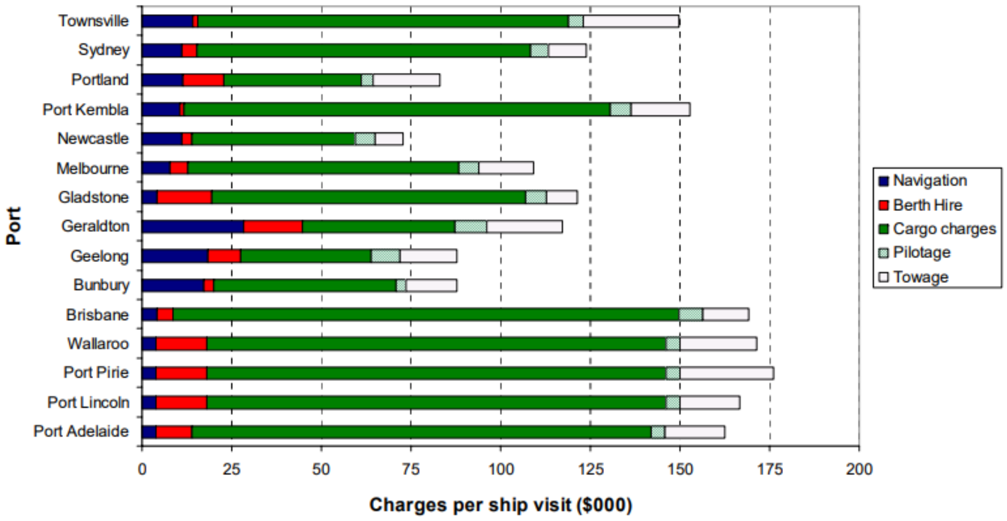

Figure 3. Port charges per ship visit for dry bulk vessels visiting selected Australian ports (Source: Meyrick and Associates (2007)).

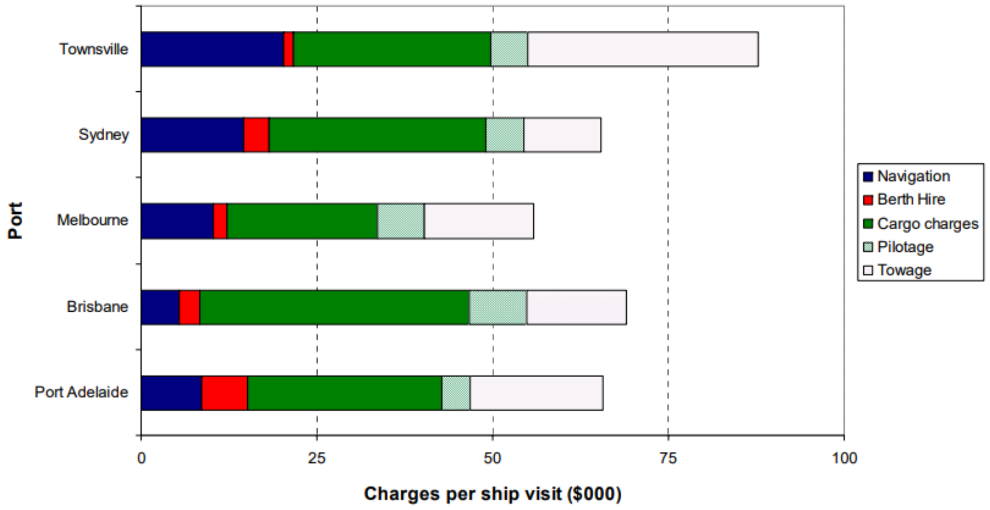

Figure 4. Port charges per ship visit for container vessels visiting selected Australian ports (Source: Meyrick and Associates (2007)).

Ship loading rates are likely to effect total handling and freight costs through their impact on charter fees (total voyage time), demurrage fees, and port costs (berth hire fees).

Study Methods

Since load rates per vessel are partially dependent on the number of cranes loading the vessel (Figure 5), and crane numbers can vary per ship or per port, load rates need to be expressed on a per crane per hour of work basis.

Figure 5. The number of cranes loading or unloading a ship can affect the vessel load rate. On the left is a very large container ship being unloaded simultaneously by eleven on-port cranes. On the left is a bulk cargo ship being loaded by four on-ship cranes. The number of cranes used is generally a function of the ship type and the port infrastructure.

Data on bulk cargo load rates for logs were gathered by contacting industry personnel in Australia. Information from Australian sources was limited so this was supplemented with load rate information from New Zealand ports by contacting a New Zealand log marshalling company and by reviewing a recent dissertation on vessel loading (Duval 2016). Load rates have been expressed in terms of JAS m^3 per crane per hour.

Data on container load rates is gathered quarterly by the Australian Bureau for Infrastructure, Transport and Regional Economics. This data was supplemented with container load rates (TEUs per crane per hour) from New Zealand ports and other parts of the world. Although a forty-foot container is equivalent to two TEU's it takes the same time to load a forty-foot container as a twenty-foot container. For the purposes of this study crane rates can be thought of as containers per hour. To be able to express load rates in terms of JAS m^3 per hour per crane, it is necessary to have a measure of the number of JAS m^3 that can be loaded into each container.

Murphy et al. (2018) carried out three case studies on facilities on eastern Australian ports that load logs into containers. Average load volumes from these case studies were used in this analysis. Sensitivity analysis to the assumed load volumes was carried out.

Handysize bulk cargo ships often have three to four cranes on-ship. Ports with container handling facilities around Australia appear to use two to four cranes to load ships. Handysize ships can handle up to 30,000 JAS m^3. As well as comparing load rates on a JAS m3 per crane per hour basis we will also compare them on the number of loading hours required per vessel assuming the utilisation of three cranes per vessel and loads of 10,000 to 30,000 JAS m^3.

Load Rates

Bulk Cargo

Load rates per crane per hour for Australian and New Zealand ports are shown in Table 1. Rates vary from 90 to 190 JAS m^3 per hour. Average load rates for Australia, adjusted for grade and length, are about 140 JAS m^3 for loads delivered to shipside by road legal trailers and about 165 JAS m3 for loads delivered by wide berth trailers. These averages are slightly higher than the New Zealand average (130 JAS m^3) but shipside tallying and scanning of log tickets is also part of New Zealand loading operations.

Table 1. Bulk cargo log loading rates for Australian and New Zealand ports.

Port	Load Rate (JAS m^3 per hour per crane)	Comments
Gladstone, QLD	140 to 145	
Portland, VIC	130 to 140	
Albany, WA	148	
Unspecified Australian ports	190	Long sawlogs, wide berth trailers
ditto	140	Short sawlogs, wide berth trailers
ditto	130	Long pulp logs, wide berth trailers
ditto	110	Short pulp logs, wide berth trailers
ditto	160	Long sawlogs, road legal trailers
ditto	120	Short sawlogs, road legal trailers
ditto	110	Long pulp logs, road legal trailers
ditto	90	Short pulp logs, road legal trailers
Averages for Australia*	165 and 140	
Marsden Point	133	
Tauranga	162	
Gisborne	157	
Napier	143	
New Plymouth	135	
Wellington	122	
Picton	115	
Nelson	130	
Lyttelton	107	
Timaru	115	
Port Chalmers	122	
Average for New Zealand	130	

* Wide berth trailers and road legal trailers

Logs in containers

Container load rates

Tongzon (1995) compared container load rates for 23 ports around the world. These included five Australian ports. Load rates ranged from 13.1 to 44.0 and averaged 24.8 TEU's per crane per hour. Fifteen years later in a review of container productivity at New Zealand ports load rates were reported for 47 ports around the world (Figure 6) (Ministry of Transport 2011). The average load rate for the five Australian ports included in the review was 28.5 containers per crane per hour. By mid-2015 the average load rate for these same five Australian ports was 34.1 containers per hour. This was 4.4 containers per hour less than the New Zealand average (Ministry of Transport 2016).

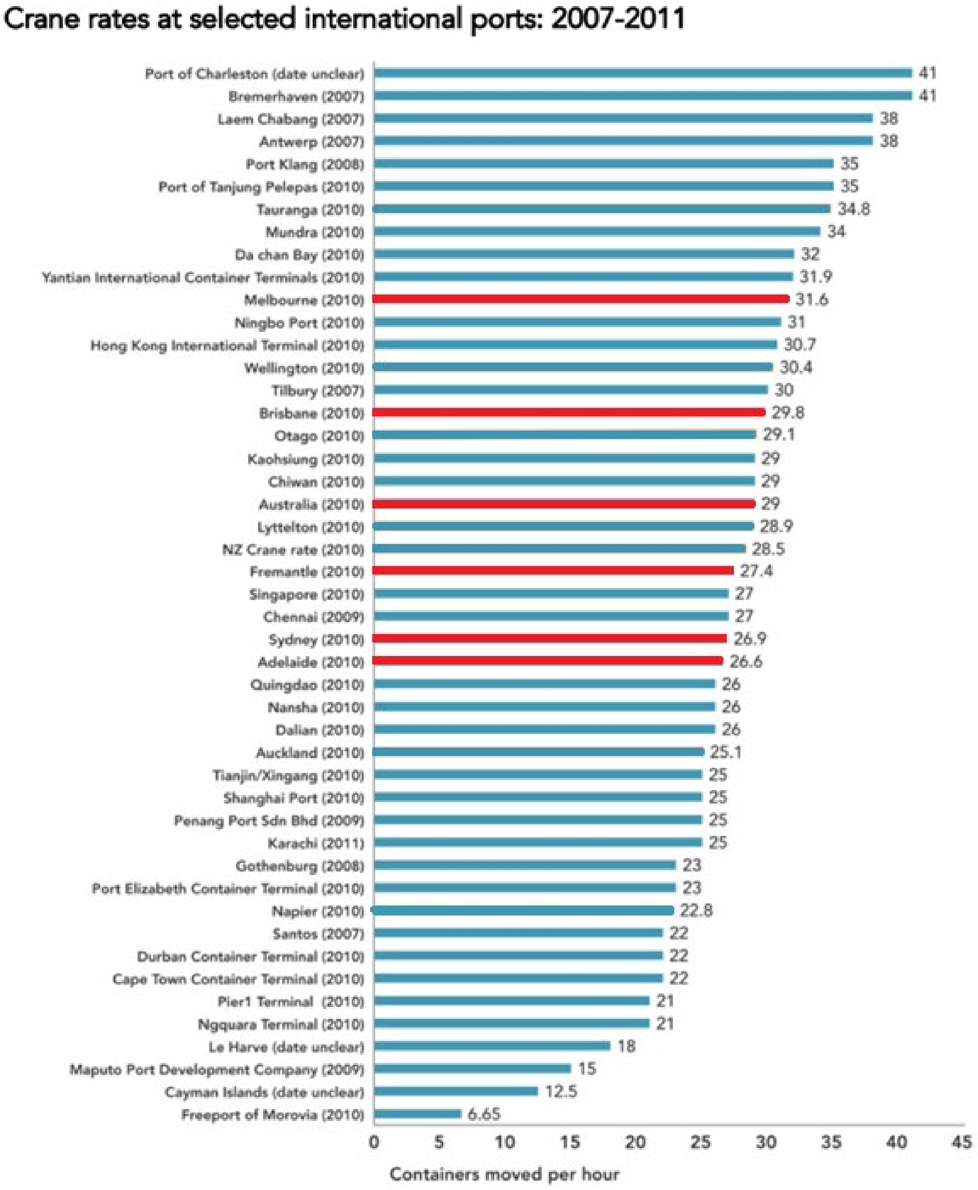

Figure 6. Container load rates for selected international ports, including five Australian ports (Melbourne, Adelaide, Fremantle, Brisbane and Sydney). Source: Ministry of Transport (2011).

Average weight and volume per container

Weight and volume were collected for 110 container loads of logs put into containers at three eastern Australian logyards. The average volume per container was 24.5 JAS m^3 and the average weight was 26.67 tonnes (Table 2). Volumes and weights varied with species, location, log length and grade (Murphy et al. 2018).

Table 2. Weight and volume statistics for three eastern Australian log yards which load logs into containers

Logyard	Number of containers	Volume per container (JAS m^3)	Weight per container (tonnes)
A	53	21.59	25.94
B	25	28.20	28.23
C	32	26.43	NA
Overall Average	110	24.50	26.67

Load rates for logs in containers

Based on an average number of containers loaded per crane per hour (34.1) and the average volume per container (24.5 JAS m^3) average load rates of 835 JAS m^3 per crane per hour can be estimated for logs in containers. The range in estimated load rates could vary by plus or minus 200 JAS m3 per hour per crane based on the variation in container load rates between Australian ports shown in Figure 6 and the variation in volumes per container shown in Table 2.

System Comparisons

Estimated load rates (JAS m^3 per hour per crane) and ship loading times are substantially different when logs are loaded onto ships in containers versus when they are loaded as bulk cargo (Figures 7 and 8).

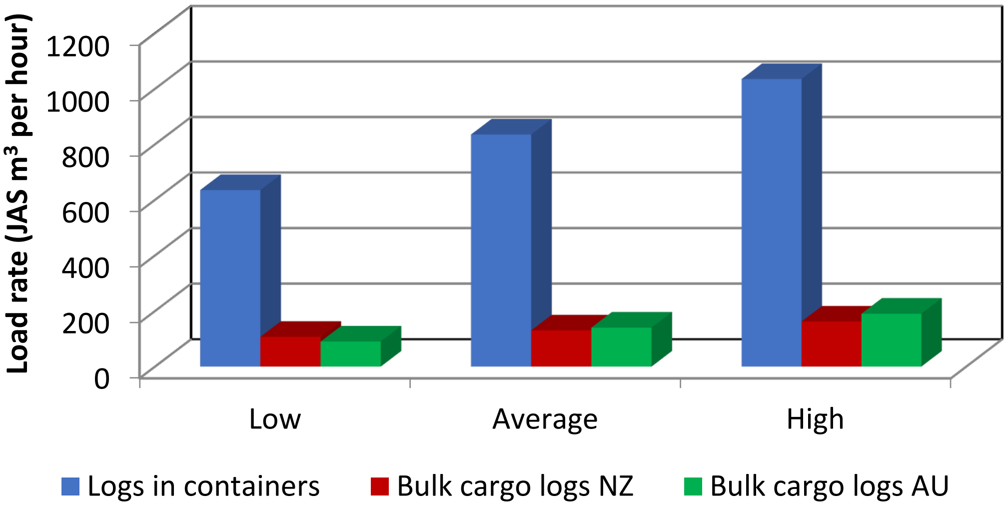

Figure 7. Estimated load rates for logs loaded in containers versus as bulk cargo.

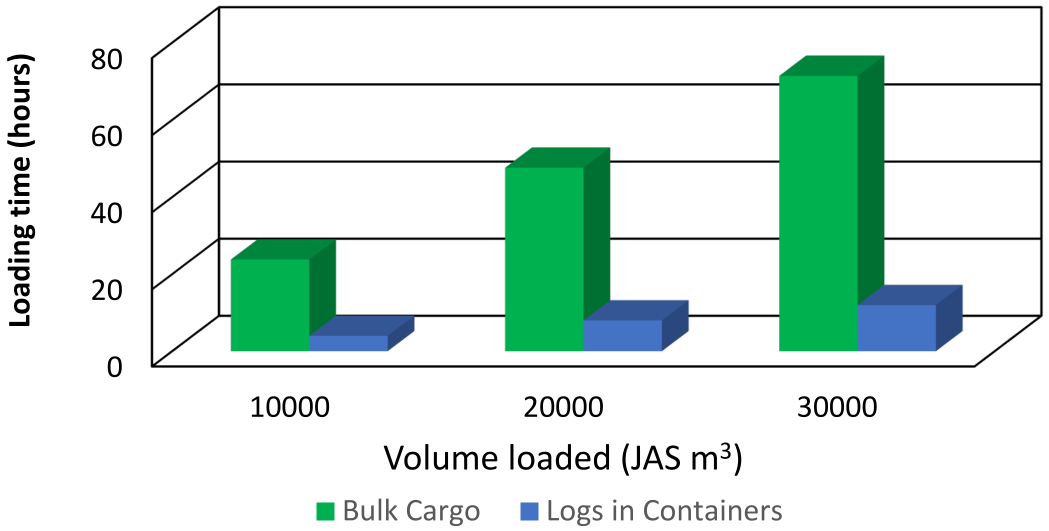

Figure 8. Estimated loading time for various load sizes for logs loaded in containers versus as bulk logs.

Load rates, on average, are about six times faster when logs are loaded in containers than when they are loaded as bulk cargo.

There is an opportunity to further increase load rates for logs in containers, however. Containers with logs in them are frequently loaded onto ships partially full; they reach their weight limit before they reach their volume limit (Figures 9 and 10). Weight limits for 40 ft dry cargo containers are set by an international shipping convention (SOLAS)[3] at 27,600 kg or less depending on the road or rail transport regulations of the exporter's or importer's country.

Figure 9. Huangdao Container Terminal in China showing containers that are ¾ "full" due to 25 metric ton weight restrictions. (Source: tptforests.com)

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[3] http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx (accessed 16 August 2018)

Figure 10. The two containers on the left and right of the photo are “full”, having reached their maximum allowable weight limit.

University of the Sunshine Coast are currently conducting trials to determine what realistic volume gains per container can be obtained from removing bark and partial drying of logs before loading them into containers. Potential increases of 40 to 60% may be possible. If this can be achieved load rates of 1100 to 1300 JAS m^3 per crane per hour could be possible. Results of the debarking and drying trials will be reported in 2019.

Discussion and Conclusions

Hummels (2007) commented that containerships are much quicker for loading and unloading than with bulk cargo. This comment is supported by our analysis which showed that average load rates for logs in containers were up to six times faster than those for bulk cargo logs. With debarking and partial drying of logs load rates could be as much as 10 times faster. Faster load rates should mean shorter voyages, lower port costs and reduced likelihood of demurrage fees.

So why aren’t more logs exported in containers? Loading logs into containers before they are loaded onto ship is an additional step in the forest to customer supply chain and requires time, space and cost. A 30,000 JAS m^3 load could be loaded onto ship in containers in a half day. Based on times reported in Murphy et al. (2018) it would take 13 to 27 days to stuff this volume of logs into containers. One container loading operator in eastern Australia has commented that much more space is required for container loading operations; space is required to store the empty containers, to store the logs, and to store the loaded containers. Costs for loading logs into containers have been also estimated by Murphy et al. (2018) to be in the order of \$4 to \$10 per JAS m^3.

The economic trade-offs between lower shipping and port costs and the additional costs of loading logs into containers is the subject of a separate FWPA funded project. This will be reported in 2019.

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Progress Report 5a: Quantification of the effect of season, debarking and drying on log quality parameters, container load capacity and sapstain formation

November 2018

Executive Summary

The project is on target for completion in Q2 2019.

Background

- Ship loading and unloading rates (JAS m^3 per hour) are substantially higher with containers than with bulk log handling methods. Load capacity for logs in containers tends to be weight-limited rather than space limited.
- Debarking of logs appears to be a viable alternative to methyl bromide for meeting phytosanitary requirements for some markets. Removing bark reduces the risk posed by unprocessed raw wood with bark being used as a pathway for the introduction and spread of arthropod pests and nematodes through international trade. Removal also facilitates the inspection of logs for phytosanitary purposes.
- Removing bark, however, also increases the rate of drying of logs and the ingress of decay and sapstain forming fungi.
- The economics of debarking may be sensitive to value losses associated with sapstain.

Containers loaded with logs often reach their weight limit before they reach their space limit. The containers on the far left and far right of the above photo are "full". More logs can only be loaded if the weight of individual logs can be reduced.

Objectives

- Quantify the effect of season of the year on container load capacity as measured in JAS m^3 per container.
- Quantify the effect of in-forest log debarking and in-forest log drying on container load capacity and load rates.

- Assess the effect of bark removal on the rate of sapstain formation on logs of two genera [Araucaria and Pinus] for a range of:
  - locations in the supply chain (in forest, in open air “at port”, in container),
  - locations within Australia (Qld, WA),
  - season of the year, and
  - time since harvesting (0 to 50 days).
- Identify potential sapstain prevention strategies and treatments through an international literature search and remote interviews with treatment specialists in Australia, New Zealand, South Africa, Chile, and North America.

<u>Progress to Date</u>

Trials have been established and data collected on *Araucaria cunninghamii* and *Pinus elliottii x P. caribaea* hybrid logs for two complete seasons (Autumn and Winter) in Queensland. A trial has also been established and data collected on Pinus radiata logs[1] for one complete season in Western Australia (Winter). Data collection for the Spring season in Queensland and Western Australia is currently underway.

Pinus radiata logs in container in debarking, drying, sapstain study in Western Australia

Full data analysis on the trials will not be carried out until data collection is completed for the four seasons in Queensland and three seasons in Western Australia. <u>Preliminary</u> data analysis, however, has provided the following findings:

- Bark weight remaining on fresh logs after harvesting was 6.7% for radiata pine, 8.4% for the hybrid pine (average of Autumn and Winter measurements) and 17.0% for Araucaria (average of Autumn and Winter measurements) of the overbark weight.

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[1] Log size for the Western Australian trial is small (~170 mm).

- Debarking fresh logs would be expected to increase conversion rates (m^3 ub per tonne) by 7%, 9% and 20% for radiata pine (small logs), hybrid pine and Araucaria, respectively.
- Drying rates (winter measurements only) were 1.7 to 6.1 times greater with the bark off than with the bark on for open air treatments for hybrid pine and Araucaria.
- When the same species were stored in containers the logs gained in weight and, surprisingly, the weight gain was greater for logs with bark on than for logs with bark off.
- All hybrid pine logs had sapstain within four weeks in winter regardless of treatment.
- The incidence of sapstain was slightly higher with bark off than with bark on for hybrid pine in the open air treatments.
- Sapstain was negligible for all treatments in Araucaria in winter.
- Insects were found within 10 days in both the bark on and bark off open air treatments for hybrid pine in the autumn and winter. No insects were found in Araucaria open air treatments in autumn or winter. Insects appeared in the container treatments for both hybrid pine and Araucaria after 30 to 40 days in Autumn but not in Winter.

Araucaria disc being collected for Debarking, Drying, Sapstain study in Queensland

It is not unexpected that the above results may change after more trials have been completed and after more detailed analyses have been carried out.

The economics of debarking may hinge on its impact on sapstain formation. A web-based search found no quantitative information on log value losses associated with sapstain. A questionnaire, seeking quantification of the impacts of sapstain on log price, was prepared and sent to log buyers and log sellers of appearance grade, structural grade and pulp grade logs in Australia and New Zealand. Eighty grade related responses have been received from buyers and sellers to date. Additional data is expected before the end of Q4 2018. Data analysis will be completed in Q1 2019.

Progress Report 5b: Quantification of woodchip ship loading rates and compaction factors

November 2018

Executive Summary

The project is on target for completion in Q2 2019.

Background

- In 2017 Australia exported close to 14 million cubic metres solid wood volume equivalent of wood chips (~7.4 million bdmt).
- Shipping and port handling costs are key costs in the forest products value chain. Costs can be affected by, among other things, ship loading rates and volumes loaded and transported.
- Methods that increase compaction increase the volume that can be transported.
- A review of the literature reveals very little information on woodchip ship loading rates, and even less on methods that increase compaction factors.

Objectives

- Increase the forest industry's understanding of woodchip ship loading rates and the levels of compaction that can be achieved.
- Identify factors that affect loading rates and load compaction for bulk materials.
- Explore the possibility of developing a simple model to predict compaction factors.
- Identify best practices for woodchip loading systems at Australasian ports.

Progress to Date

A preliminary literature review to determine compaction levels that can be achieved with woodchip-like materials using a range of techniques such as compression, vibration, fluttering, etc. has been undertaken.

A D4 tractor that is lowered into a ship hold to move and compact woodchips

Contact has been made via personal visits, phone calls and emails with export woodchip handlers in Bunbury (WA), Albany (WA), Portland (VIC), Geelong (VIC), Burnie (TAS), Brisbane (QLD), Gladstone (QLD), Port Melville (NT), Marsden Point (NZ), Coos Bay (Oregon, USA), Montevideo (Uruguay) and Brazil to gather information on indicative ship loading rates and compaction factors, the type of loading systems being used, and the type of material being loaded (e.g. plantation hardwood, softwoods, etc.). Most of the contacts have provided some information that is relevant to the project. A few of the contacts have provided information on load rates and compaction factors for at least 10 ship loads.

Data collection and analysis will not be completed until the first half of 2019.

Woodchip piles at the Port of Albany in Western Australia

Preliminary findings include:

- There is a wide range of equipment used to move woodchips from storage piles to the ships hold. Some are fixed installations, some are mobile. Some are purpose built for moving woodchips. Some are designed to handle a wide range of materials; e.g. woodchips, grain, ore, etc.
- Load rates vary considerably – from 300 tonnes per hour to 1000 tonnes per hour per feeder.
- Contacts indicate that there is a trade-off between load rates and compaction factors. For example, one port could load at 700 to 750 tonnes per hour but loaded at 600 to 650 tonnes per hour to get the best load compaction.
- Stowage factors (cubic feet per green tonne) or compaction factors (cubic feet per bone dry metric tonne) are reported as measures of load efficiency. These are affected by moisture content (which is effected by season of the year), species (which effects density), load rates (as per the above comment), loading equipment (e.g. use of jetslinger with or without deflection plates, tractors or bobcats in the hold), loading practices (e.g. load 75% and then put a compaction machine in the hold), and port characteristics (e.g. if ship leaves a port partially loaded due to the port being shallow it will have a high compaction factor since compaction is determined by dividing the available loading volume by the loaded weight). Compaction factors ranging from 203 to 128 cubic feet per bone dry tonne were reported. More than one contact reported being able to load an additional $200,000 worth of woodchip cargo as a result of improvements to compaction factors.

Jet slingers distributing chips to a woodchip pile (top) and undergoing repairs to a deflector plate (bottom).

In early 2019 a small-scale model of a jet slinger will be developed to evaluate the effect of alternative designs on compaction factors. The results of the evaluation will be incorporated into a simple compaction prediction model.

In early 2019 a technical review will also be carried out on the use of robotics, sensor systems, and automation for increasing bulk handling ship loading rates and compaction factors in non-forest industry products (e.g. grain, coal, iron ore).