CRC P3 REPORT

OPTIMISATION STUDY – QUANTIFYING THE VALUE RECOVERY IMPROVEMENT USING IN-FOREST OPTIMISATION

Damian Walsh

1 INTRODUCTION

Australia faces a substantial supply deficit in softwood roundwood logs in the future due to the raw material needs of the domestic sawn timber and pulp markets having outpaced new plantation establishment over the last two decades. In addition, much of the current available supplies of roundwood logs from Australia's softwood plantations have already been sold through long-term wood supply agreements with processors. As a result Australian forest owners are constrained in their ability to maximize revenues and profits by not having additional volumes of wood to sell. Instead they are being forced to focus on other ways of maximizing revenues and profits including reducing costs, increasing productivity or increasing prices. However, another aspect that should also be considered is to maximize the value of the forest at the time of harvest to in turn maximize revenues and profits.

Over the last few years some forest owners who have adopted delivered sales [1] have shown an interest in using in-forest optimisation technology now widely available on the most modern harvesting machines to collect data and optimise the number and volume of log products cut at each harvesting operation to fulfil customer orders on a weekly and/or monthly basis.

Individual tree stems can be cut into various combinations of log product grades. The basis for adoption of optimisation technology is that mechanised harvester operators have a limited capacity to select the optimal mix of log products and therefore cannot effectively maximise recovered value from harvesting operations [2]. With the aid of optimisers (a component of machine mounted on-board computer systems or OBC's), installed on harvesters, competent operators, and the benefit of being able to refine cutting instructions through desktop simulations using real and relevant stem data, the harvester can be programmed to determine the best log combinations to maximise the total value of the mix of log products cut from each stem. This in turn provides the forest grower with improved value recovery and financial returns from their harvesting operations [2].

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[1] Delivered sales refers to sales of log products to customers (sawmills and/or pulpmills) at the mill door or a roadside, where the forest owners is responsible for the costs of harvesting and/or haulage of the log products to the customer. In many forest regions these types of sales have replaced the more traditional stumpage sales which refer to sales of log products at the stump where the harvesting and haulage of the log products is the responsibility of the mill owner or customer. Under stumpage sales the forest owner is not the primary controller of the harvest and haulage operation.

[2] Williams, D. 2009 *Improving business performance in softwood plantations.* In "Proceedings of the Biennial Conference of the Institute of Foresters of Australia", IFA Caloundra.

Forests New South Wales (FNSW) invited the CRC for Forestry, Program 3 – Harvesting and Operations (CRC P3) to undertake a study of use of optimising technology in harvest machines. The objective of this study was to implement a workable in-forest optimisation system, and demonstrate and quantify the value recovery improvement that may be achievable through its use as part of an overall value recovery framework.

Comparisons of value recovery were made between:

- Results of Atlas CRUISER inventory analysis by product yields.
- Actual harvested yields by log product **without** optimisation.
- Actual harvested yields by log product **with** optimisation.

Harvest machine productivity was also measured and productivity comparisons made between harvesting with and without optimisation.

2 STUDY DESCRIPTION

CRC researchers worked with FNSW staff at Bathurst to establish two 100-tree plots in a 34-year-old radiata pine plantation that had been thinned twice and was of uniform stand and site conditions [3].

Every tree in the two 100-tree plots was inventoried by FNSW inventory crews (using ATLAS Cruiser tree description methodology).

The trees on the first plot were harvested as per normal operations, effectively without optimisation, (the 'Control Plot') while the trees on the second plot were harvested using optimisation (the 'Optimised Plot'). Each plot was harvested using a Valmet 475 [4] fitted with a Waratah HTC624C processing head. The machine was also fitted with a Timbermatic/TimberRite 300 OBC and optimiser that allowed each stem to be bucked to optimal value based on a user-defined price matrix (or apt file [5]).

The Control Plot was cut first (on 18th January, 2011). The harvester's optimiser was used as previously set-up by the operator with an apt file that included a value/price matrix that in practice used the quality buttons to mimic the actions of length pre-set buttons, thereby allowing only the operator to select the product and length to be cut.

After the first plot was cut, the operator was introduced to a new apt file, and the harvester was set-up to use the OBC's optimiser to suggest the highest value bucking solution to be cut based on the wood quality code system (Table 1) and a new price matrix (Figure 1), subject to the actual and predicted physical dimensions of the tree. The operator was given time to get used to the new set-up and through a consultative process with the operator some

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[3] Stand and site conditions were very good. The stand was relatively high yielding with trees of good form and quality. The site was flat with no obstacles or rock present.

[4] 2007 model, Cummins T3 330hp, 3500hrs.

[5] The apt file is the cutting instructions that the harvester's optimiser uses to determine the best combination of products to cut to maximise the value of each stem.

adjustments were made to the apt file and wood quality code system to ensure an improved (smooth and consistent) work process.

The Optimised Plot was then cut (on the 30th March, 2011) using the harvester's OBC and optimiser with the revised apt file and work process whereby the operator only selected the wood quality of the next stem piece to be cut, (if different from the default setting), or decided whether to override the optimisers' suggestion.

A detailed time and motion study was completed for the harvesting phase (refer APPENDIX 1 for time element definitions) for each plot and a record was made of the products cut and their dimensions. All products were segregated at the stump and into different stacks by product and/or log sort at roadside and tracked across customer weighbridges to determine exact yields from each plot.

2.1 Optimiser and Wood Quality Code System Settings

2.1.1 Wood Quality Codes and Log Specifications

The development of a simple system of wood quality codes was essential to the use of the harvester's optimiser. The wood quality codes that were used in the cutting of the Optimised Plot are defined in Table 1. They are based on the regional log specifications for each customer and product as defined in the respective wood supply agreements (Table 2).

Table 1: Definition of wood quality codes used in the Optimised Plot

<table>
<tr><th>Quality Code</th><th>Multiple Sweep or Wobble</th><th>Max Branch Size</th><th>Nodal Swelling</th><th>Sweep</th><th>Butt Flare</th><th>Fluting</th></tr>
<tr><td>Q1 (or A) Pruned Sawlog [6]</td><td rowspan="2">17% (or SED/6) over log length</td><td>No Branches</td><td rowspan="4">N/A</td><td rowspan="2">25% (or SED/4) over log length</td><td rowspan="4">25% of Change in Diameter (or Diameter/4)</td><td>Nil</td></tr>
<tr><td>Q2 (or B) Sawlog</td><td>100 mm
(50 mm for small diameter logs, 75 mm for medium diameter logs & veneer logs)</td><td rowspan="3">N/A</td></tr>
<tr><td>Q3 (or C) Salvage Sawlog [6]</td><td>33% (or SED/3) over log length</td><td>120 mm</td><td>50% (or SED/2) over log length</td></tr>
<tr><td>Q4 (or D) Pulpwood or Chiplog</td><td>50% (or SED/2) over log length</td><td>Unlimited</td><td>50% (or SED/2) over log length OR Straight enough to pass through a cylinder 600 mm diameter & 3.6 m long</td></tr>
</table>

[6] Note that 'Q1 (A) Pruned Sawlog' and 'Q3 (C) Salvage Sawlog' was not used in the study as no pruned or veneer, nor an export/salvage sawlog product was cut. However, it is included in Table 1 as it possible that it could be at some time in the future.

Table 2: Wood quality codes as they apply to the regional log specifications

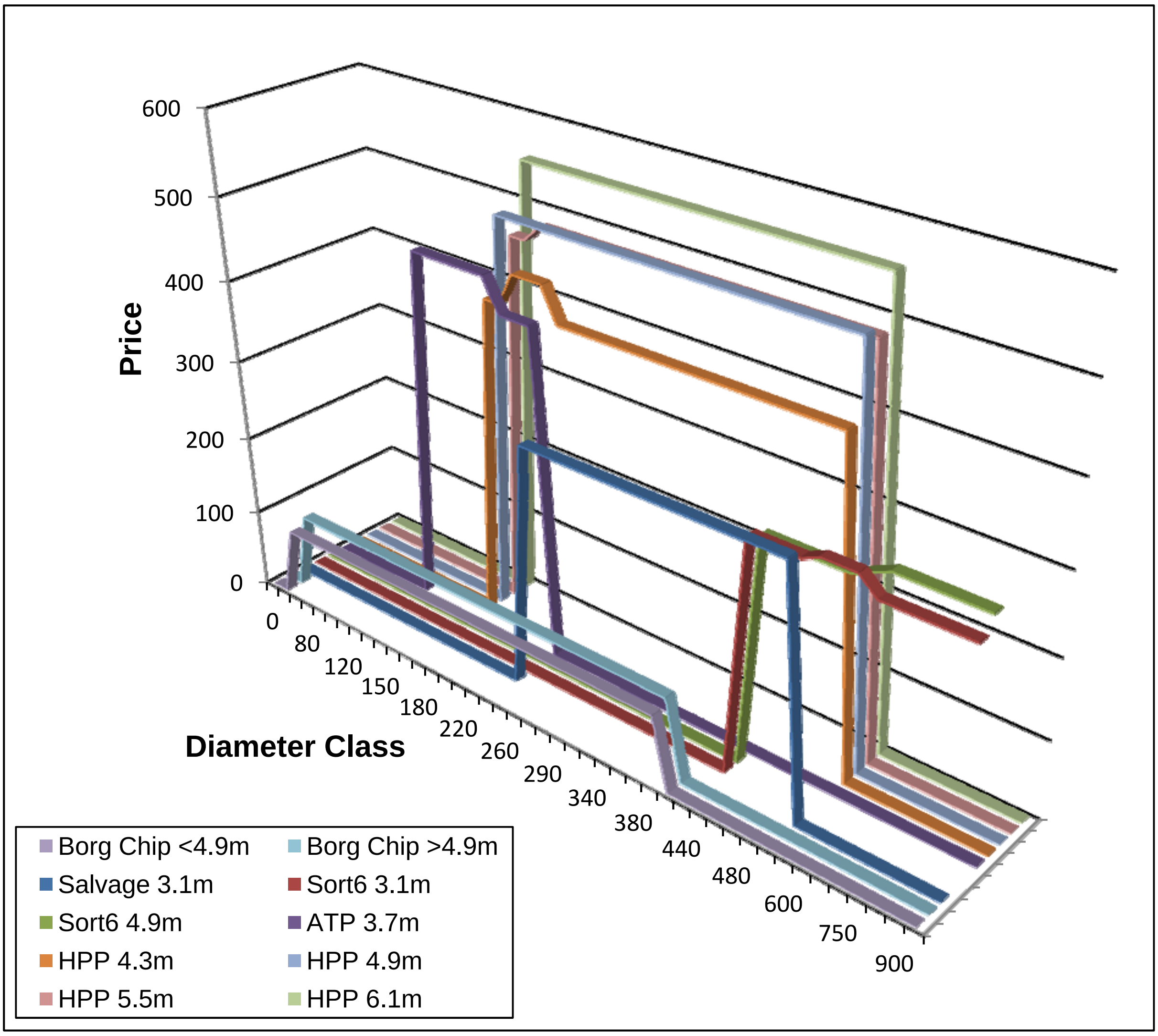
<table>
<tr><th rowspan="3">Quality Code</th><th rowspan="3">Product Group</th><th rowspan="3">Product Name</th><th colspan="3">Diameter (mm)</th><th rowspan="3">Allowable Target Lengths (m)</th><th colspan="4">Knots</th><th colspan="2">Sweep</th><th>Nodal Swelling</th><th>Blue Stain</th></tr>
<tr><th rowspan="2">Min (SEDUB)</th><th rowspan="2">Max (SEDUB)</th><th rowspan="2">Max (LEDUB)</th><th colspan="2">Knot Size</th><th>Spike Knots</th><th rowspan="2">Knot Cluster</th><th rowspan="2">Max (CDUB)</th><th rowspan="2">Max (SEDUB)</th><th rowspan="2">Max (mm)</th><th rowspan="2">Max Cross-section (%)</th></tr>
<tr><th>Max (mm)</th><th>Max (SEDUB)</th><th>Max (mm)</th></tr>
<tr><td rowspan="7">Q2</td><td rowspan="7">SAWLOG</td><td>Sort 6 Salvage/Case Sawlog</td><td>~500</td><td colspan="2">Unlimited</td><td>2.5, 3.1, 4.3, 4.9, 5.5 & 6.1</td><td>100</td><td colspan="3">N/A</td><td colspan="2">Max. 100mm over log length</td><td rowspan="5">N/A</td><td>N/A</td></tr>
<tr><td>HPP Lrg Sawlog</td><td>351</td><td>N/A</td><td>550</td><td>4.3, 4.9, 5.5 & 6.1</td><td></td><td colspan="3" rowspan="4">N/A</td><td rowspan="6">N/A</td><td rowspan="4">25% (or SED/4) over log length</td><td rowspan="2">50%</td></tr>
<tr><td>HPP Sml Sawlog</td><td>180</td><td>350</td><td rowspan="4">N/A</td><td>4.3, 4.9, 5.5 & 6.1</td><td>75</td></tr>
<tr><td>ATP Sawlog</td><td>150</td><td>180</td><td>4.9 & 5.5</td><td>50</td><td rowspan="2">20%</td></tr>
<tr><td>ATP 3.7 Sawlog</td><td>150</td><td>250</td><td>3.7</td><td>50</td></tr>
<tr><td>Auswest Sml Sawlog</td><td>160</td><td>279</td><td>3.65</td><td>60</td><td rowspan="2">N/A</td><td>120</td><td rowspan="2">N/A</td><td rowspan="2">N/A</td><td rowspan="2">30</td><td rowspan="2">10%</td></tr>
<tr><td>Auswest Lrg Sawlog</td><td>280</td><td rowspan="6">N/A</td><td>450</td><td>3.65</td><td>80</td><td>160</td></tr>
<tr><td rowspan="2">Q3</td><td>INDUSTRIAL / EXPORT</td><td>Export Sawlog</td><td>120</td><td rowspan="2">N/A</td><td>3.92</td><td>120</td><td colspan="3">N/A</td><td colspan="2">50% (or SED/2) over log length</td><td rowspan="5">N/A</td><td>50%</td></tr>
<tr><td>LANDSCAPE / DUNNAGE / SALVAGE</td><td>Salvage Sawlog</td><td>260</td><td>2.5 & 3.1</td><td>150</td><td colspan="3">N/A</td><td colspan="2">50% (or SED/2) over log length</td><td>50%</td></tr>
<tr><td rowspan="4">Q4</td><td rowspan="3">PULPWOOD / CHIPLOG</td><td>Borg Chip</td><td>80</td><td>450</td><td>Variable Length between 3.7 to 6.1</td><td colspan="4" rowspan="4">N/A</td><td colspan="2" rowspan="2">50% (or SED/2) over log length</td><td rowspan="2">50%</td></tr>
<tr><td>Borg Pulp</td><td>80</td><td>300</td><td>4.9</td></tr>
<tr><td>Visy Pulp</td><td>80</td><td>600</td><td>Variable Length between 3.6 to 6.1</td><td colspan="2">Straight enough to pass through a cylinder 600 mm diameter & 3.6 m long</td><td>Reasonably free</td></tr>
<tr><td>WASTE</td><td>Waste</td><td colspan="3">Any Diameter</td><td>Any Length</td><td colspan="2">N/A</td><td>N/A</td><td>N/A</td></tr>
</table>

The wood quality code definitions were determined through a process of standardisation of the various specifications through consultation with the harvester operator and FNSW regional staff. They are designed and intended to be used with a harvester's optimiser processing trees into logs only.

2.1.2 Value Matrix

The value matrices used in the study for the Optimised Plot and programmed into the apt file used by the harvester's optimiser are shown in Figure 1. The values for each log product by length and diameter class are relative values as rather than actual stumpage values. Of all the products listed in Table 2, only those products shown in Figure 1 were intended to be produced in the study.

Figure 1: Graphical representation of the value matrix contained in the apt file used in the study



2.1.3 Pre-set length override buttons

If the operator did not agree with the optimiser's suggested product to be cut from the next section of stem, they could override the optimiser by pressing one of a series of pre-set length override buttons. The pre-set length buttons that were chosen and programmed into the harvester's OBC are shown in Table 3.

Table 3: List of pre-set length override buttons used in the optimisation study

Button No.	Product Group	Product Name	Length (m)
1	Sawlog	Lrg & Sml HPP Sawlog	5.52
2			4.92
3			4.32
4		ATP 3.7 Sawlog	3.72
5		Sort6 Salvage/Case Sawlog	3.12
6	Waste	Waste	1.0

2.1.4 Bark Function

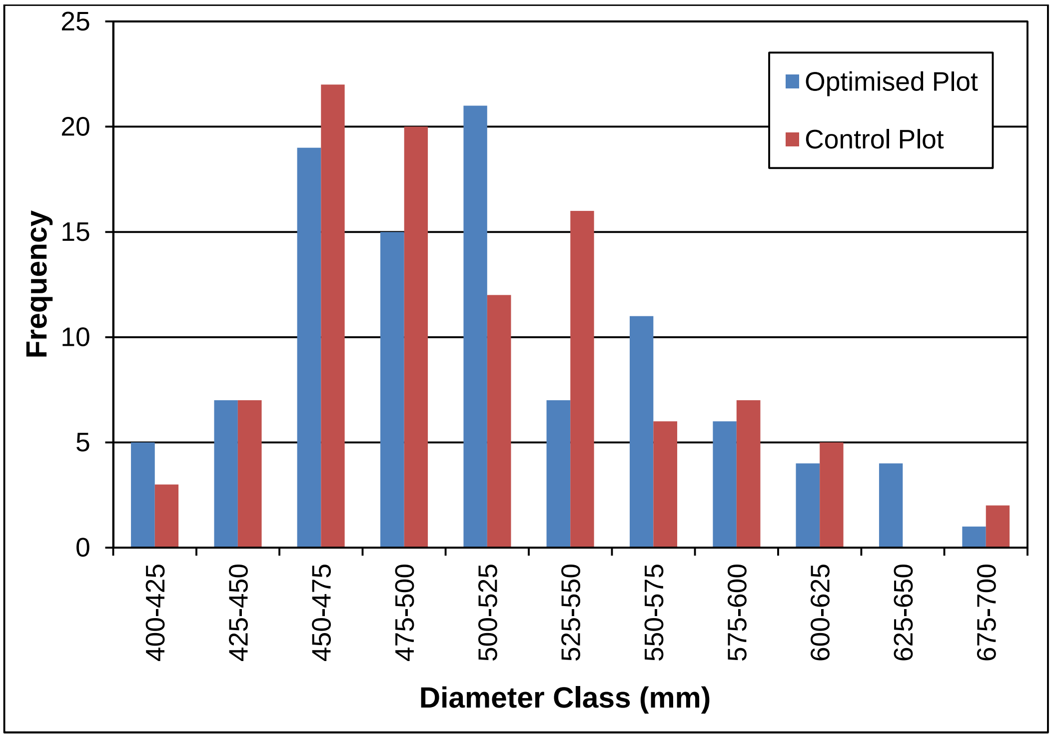
As a StanForD compliant bark function was not available for the Bathurst/Oberon *Pinus radiata* resource, the bark function co-efficients in the apt file used by the harvester's optimiser were set to zero. This indicated that diameter under-bark of the trees as measured by the harvester in the study was the same as diameter over-bark.

3 RESULTS

3.1 Plot Pre-harvest Inventory

The pre-harvest inventory on each plot revealed that they had the statistically same mean tree diameter breast height over-bark (DBHOB), height, basal area (BA) and volume, (t-test, α=0.05). However, the two plots had different areas, so as to include the same number of trees on each plot, and hence had very different stockings, total BA, and total volume per hectare on each plot. However, both plots were closely matched in terms of the range of tree sizes harvested and provided a reasonably good basis for the comparison of harvest productivity (Figure 2).

Figure 2: Histogram showing the distribution of trees by diameter class in each plot



The results of the pre-harvest inventory conducted on the plots are shown in Table 4.

Table 4: Results of pre-harvest inventory for the Optimisation Study

	Control Plot	Optimised Plot
Plot Area (ha)	0.45	0.90
No. of Trees	100	100
Stocking (stems/ha)	220	111
Mean Tree Volume (m^3)	2.1	2.2
Mean Tree Diameter, DBHOB (cm)	50.9	51.2
Mean Tree Height (m)	30.3	31.0
Basal Area (m^2/ha)	45.7	23.2
Merchantable Volume (m^3/ha)	472.2	242.1

3.2 Yields

Product yields as measured by the harvester and by customer weighbridges (with the exception of the Borg Chip product which was a stack estimate measured in the field) from both the Control and Optimisation Plots are shown in Table 5 and Table 6.

Table 5: Product yields (m^3) from the Control Plot

Product	Harvester Volume (m^3)	Weighbridge Volume (m^3) [7]	% Difference
Case/Salvage Sawlog	8.4	8.4	0.8%
Sort 6 Sawlog 4.9	2.6	3.4	-24.4%
HPP Sawlog 4.3/4.9	57.5	57.4	0.1%
HPP Sawlog 6.1	148.2	148.2	0.0%
ATP 3.7 Sawlog	5.0	4.6	8.6%
Borg Chip [8]	15.6	14.8	5.3%
Total	**237.2**	**237.0**	**0.1%**

Table 6: Product yields (m^3) from the Optimised Plot

Product	Harvester Volume (m^3)	Weighbridge Volume (m^3) [9]	% Difference
Case (Salvage) Sawlog	20.3	20.2	0.2%
Sort 6 Sawlog 4.9	0.0	0.0	0.0%
HPP Sawlog 4.3/4.9	37.8	40.8	-7.5%
HPP Sawlog 5.5	11.2	10.1	10.8%
HPP Sawlog 6.1	135.1	138.9	-2.8%
ATP 3.7 Sawlog	8.6	8.9	-3.3%
Borg Chip [8]	14.0	17.0	-17.6%
Total	**227.0**	**236.5**	**-4.0%**

As can be seen the total yields measured by the harvester and over the customer's weighbridges were very similar for both plots - within +/- 5%. This result served to provide confidence that the harvester's OBC had measured each log produced accurately in both plots.

3.3 Harvester Productivity

3.3.1 Comparison of time elements

The percentage breakdown of the time elements for harvesting and processing the two plots indicated very little difference between the results for the Control and Optimised Plots (Figure 3 and Figure 4).

[7] Converted from GMt using a conversion factor of 1.01 for January 2011.

[8] Stack estimate measured in the field, not a weighbridge estimate.

[9] Converted from GMt using a conversion factor of 1.03 for March 2011.

Figure 3: Harvest time elements for the Control Plot

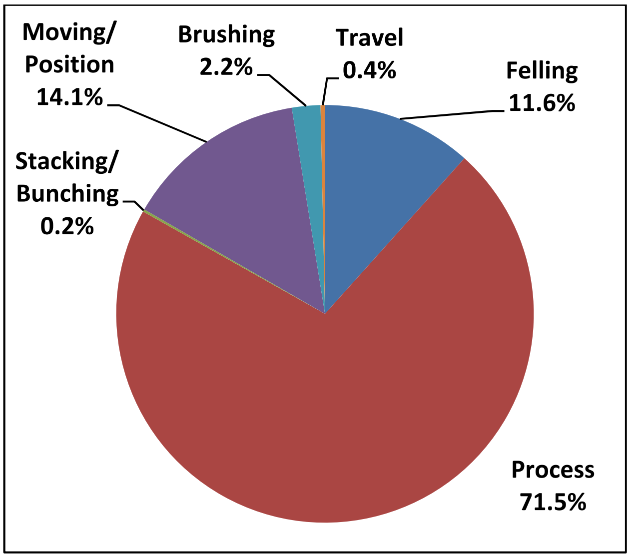
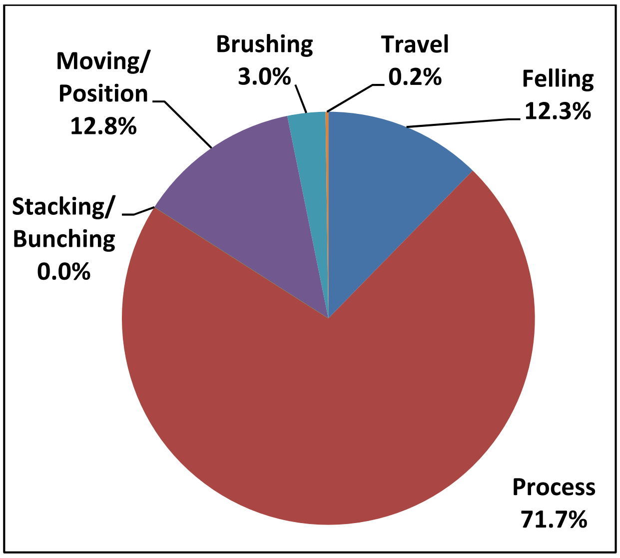


Figure 4: Harvest time elements for the Optimised Plot



3.3.2 Comparison of productivity

A comparison of harvester productivity on each plot (Table 7) showed that using the harvester's OBC and optimiser with the revised apt file and work procedure had a positive impact (19.7%) on the productivity of the harvester.

Table 7: Direct comparison of harvester's productivity in the two study plots

	Control Plot	Optimised Plot
Harvest Time (PMH_0 [10])	1.85	1.70
Total Production (m^3)	215.6	236.5
Productivity (m^3/PMH_0)	116.5	139.5

3.3.3 Regression comparison - impact of tree size

Productivity of harvest operations is highly dependent on tree size. Productivity increases, in a non-linear or declining manner, with increasing tree size up to a threshold level where productivity then starts to decrease. To support the comparison of the harvester's productivity between the plots, a comparison of productivity models taking into account the range of tree sizes harvested was completed.

In order to better isolate the impact of using the harvester's OBC and optimiser from that of other variables (or differences) between the two plots that may have affected the harvester's productivity, malformed or unusual trees, were removed from the datasets, leaving 'normal trees' [11] only (Table 8). It was anticipated that removing these trees from the analysis would provide a more

[10] PMH_0 is defined as Productive Machine Hours excluding all delays.

[11] Normal trees were defined as those trees which were not classed as edge trees, trees with double leaders or trees with broken tops, or trees that had been identified as having unusual processing times.

realistic comparison of the impact of the harvester's OBC and optimiser on harvester productivity.

Table 8: Sample sizes for 'all trees' and 'normal trees' used in the productivity analysis

	Control Plot	Optimised Plot
All trees	100	100
Normal trees	42	45

Regression models were fitted to data from 'normal trees' from each plot [12]. The independent x-axis variable was tree volume as measured by the harvester (aggregate of the volume of each log cut from each tree or processed volume) and the dependent y-axis variable was productivity (processed volume divided by total cycle time to harvest for each tree). Total cycle time was determined using pro-rata time values for time elements relatively unaffected by tree size (travel, moving/positioning, stacking/bunching and brushing/clearing) and actual felling and processing times for each tree, thereby limiting the variation in cycle time to those time elements most affected by tree size (ie. felling and processing). Model forms tested were a linear (straight-line), power curve and natural logarithm transformations (x-axis only and both x- and y-axes). Model forms were compared for goodness of fit using average bias, root mean square error (RMSE), R^2 and spread of residuals.

For both plots a natural log function of the following form gave the best fit to the data:

$$Productivity = \beta_0 + \beta_1 * \ln(Processed\ Volume)$$

The productivity models for the Control and Optimised Plots showed an R^2 of 0.40 and 0.47 respectively. Other assignable causes of variation in the harvester's productivity for 'normal trees', other than tree size, were not readily apparent from field observations, nor from the data collected.

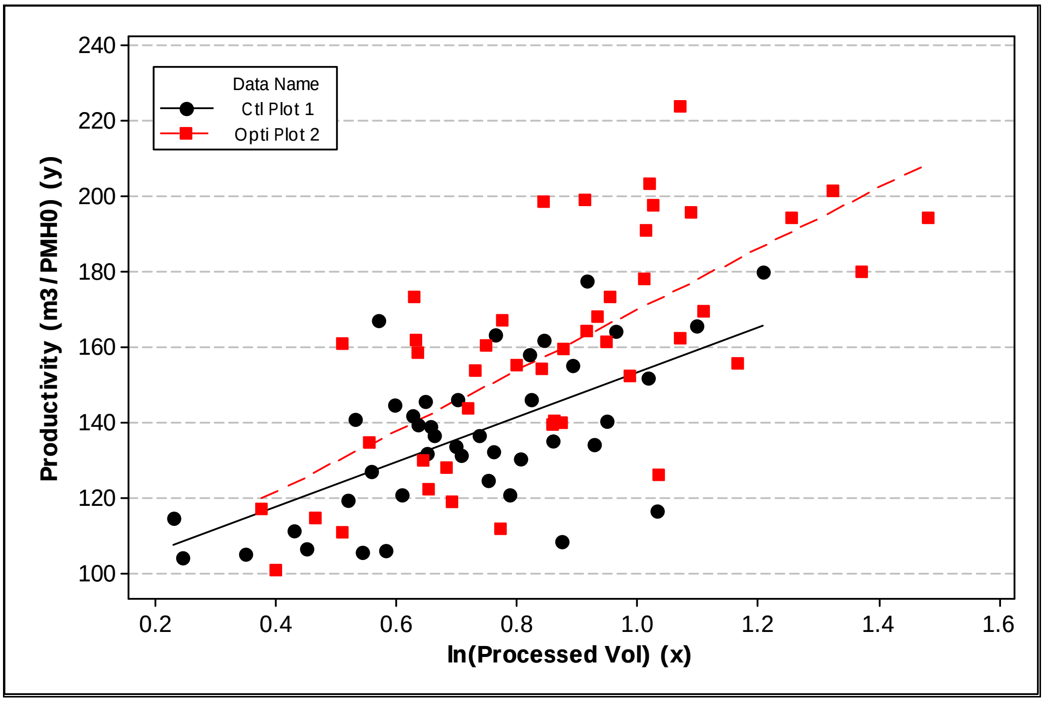
A statistical comparison of each plot's productivity model was completed using two statistical techniques, the 'Chow test' (or extra sum of squares F-test); and a single multiple regression using an indicator (dummy) variable to test for coincidence [13]. Both tests indicated that there was a statistically significant difference between the two models (α=0.05) indicating a significant improvement in productivity in the Optimised Plot (Figure 5).

At the mean 'normal tree' size (processed volume) between the two plots (2.26 m^3), the regression models indicate a modelled productivity increase of 9.3% when using the harvester's OBC and optimiser. This increase varies across the range of tree sizes in common sampled - from 4.2% at a tree size of 1.45 m^3, to 12.5% at 3.35 m^3.

[12] Olsen, E.D, Hossain, M.M. & Miller, M.E. 1998. *Statistical Comparison of Methods Used in Harvesting Work Studies. Research Contribution 23, College of Forestry, Forest Research Laboratory, Oregon State University, 41 p.*

[13] Gujarati, D. 1970. *Use of Dummy Variables in Testing for Equality between Sets of Coefficients in Two Linear Regresions: A Note.* The American Statistician, Vol.24(1), pp.50-52.

Figure 5: Scatterplot of ln(Processed Volume) vs Productivity with regressions for harvesting of 'normal trees' grouped by plot



3.3.4 Productivity of harvesting non-normal trees

It was speculated during the study that the harvester's OBC and optimiser allowed for faster processing of 'normal trees' but did not necessarily do the same for malformed or unusual ('non-normal') trees. To confirm that the increase in productivity observed for the 'normal trees' when using the harvester's OBC and optimiser was consistent across 'non-normal trees' as well, regression models were fitted to the 'non-normal trees' identified in each plot using the same methods (as above, section 3.3.3). Again, for both plots a natural log function of the following form gave the best fit to the data:

$$Productivity = \beta_0 + \beta_1 * \ln(Processed\ Volume)$$

The productivity models for the Control and Optimised Plots showed an R^2 of 0.10 and 0.03 respectively indicating variations in productivity when harvesting 'non-normal trees' were poorly correlated with tree size. The statistical comparison of the two productivity models using the 'Chow test' and a single multiple regression using an indicator (dummy) variable to test for coincidence indicated that there was a statistically significant difference between the two models (α=0.05) indicating a significant improvement in productivity in the Optimised Plot.

At the mean average 'non-normal tree' size (processed volume) between the two plots (2.30 m^3), the regression models indicate a modelled productivity increase of 19.8% when using the harvester's OBC and optimiser. This increase varies across the range of tree sizes in common sampled - from 28.8% at a tree size of 1.40 m^3, to 14.7% at 3.30 m^3.

3.4 Value Recovery

3.4.1 Data collection

Initially, value recovery was analysed using the stm files [14] collected from the harvester for each plot. However, because the Optimised Plot had greater numbers of larger trees, and therefore larger size logs, more volume of lower value 'Sort 6 Case/Salvage Sawlog' was cut, as more butt logs exceeded the maximum large-end diameter (LED) for higher value sawlogs, adversely impacting a meaningful value recovery comparison between the two plots over a small sample.

In order to get a better and more meaningful comparison of value recovery the stm files collected representing the trees in the Control Plot were 're-cut' using the John Deere TimberMatic H-09 Harvest Simulator v1.9.9 and the same apt file as used in the Optimised Plot. This was done as a desktop exercise for each tree with the assistance of the video recording of the Control Plot to provide a visual guide for tree form. The data generated in the Simulated Plot was a representation of what would have been cut from the Control Plot had the harvester's OBC and optimiser been used.

Each log cut using the harvest simulator (Simulated Plot) was recorded and had a value placed upon it representing its estimated stumpage price [15] in the current market. Similarly, the logs actually cut from the Control Plot in the study, and the log trace results of the Pre-harvest Inventory also had stumpage values placed on them. For each dataset, these values by log were multiplied by the individual log volumes recorded, and summed to give a total recovered value for each tree. The value recovery data from the Simulated Plot (collected using the simulation optimiser) was then compared with the value recovery data from the Control Plot (collected without using the harvester's OBC and optimiser) and the benchmark Pre-harvest Inventory results.

3.4.2 Comparison of Yields

A comparison of yields between the Control Plot, the Simulated Plot and the Pre-harvest Inventory (Figure 6) showed that using the optimiser (Simulated Plot) produced a slightly greater volume of the higher value structural sawlogs than from the actual harvest without using the optimiser (Control Plot). Both the Simulated Plot and Control Plot cut more volume of the higher value products, and more volume in total, than the Pre-harvest Inventory analysis.

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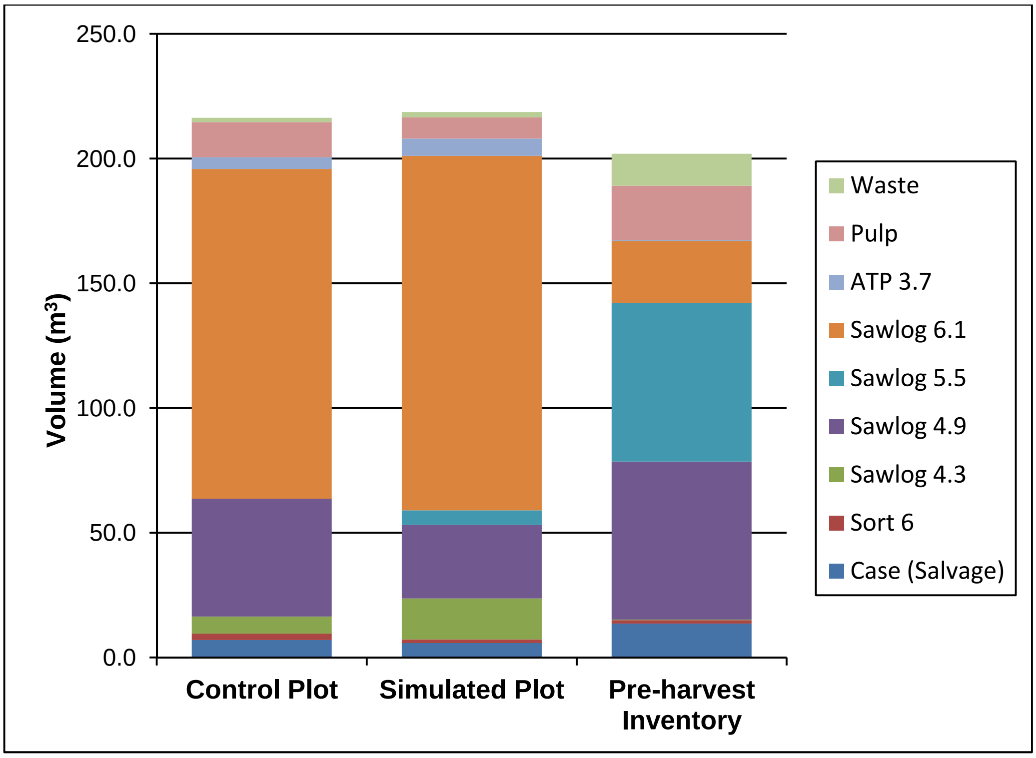
[14] The stm files (or stem files) are the set of files created by the harvester's OBC that stores all information (measured lengths and diameters, products cut, etc.) associated with each stem cut by the harvester. They are generally organised as one stem per file.

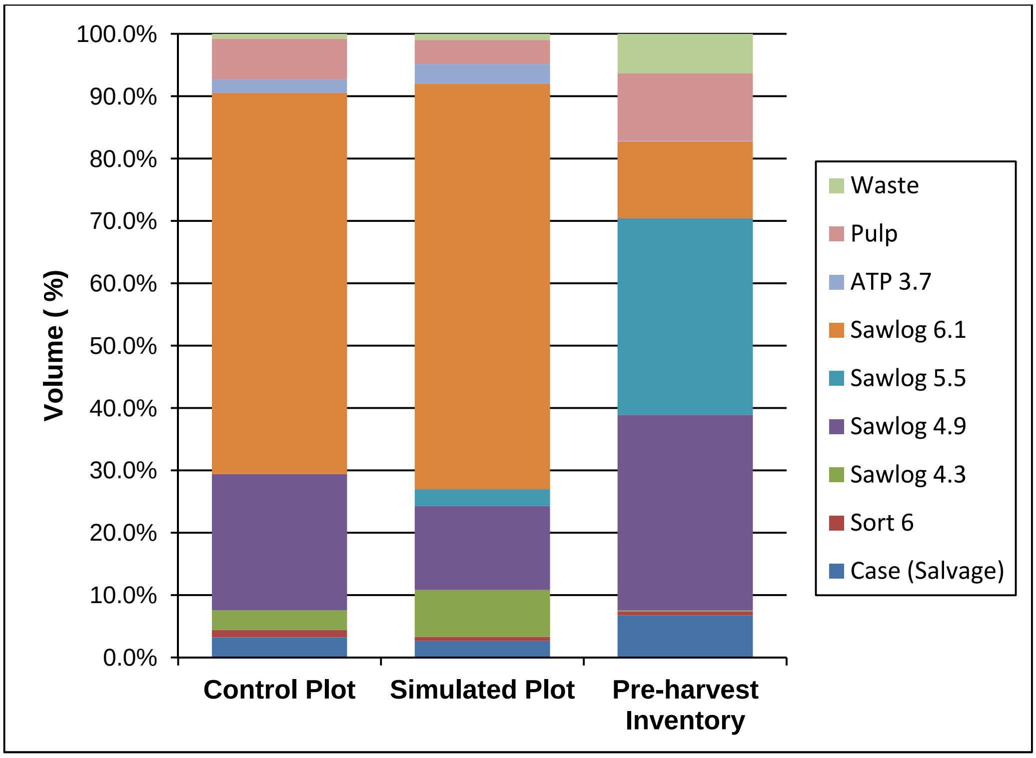
[15] The stumpage price applied to each log product was a generalised regional residual stumpage price as at 1st April 2010. It was calculated by taking the delivered price by product and/or customer and subtracting the regional average delivery charge for each customer. As a result the stumpage price used does not accurately reflect the real residual stumpage price for the study site.

Figure 6: Comparison of yields by product (m^3)



The increase in sawlog volume in the Simulated Plot compared to the Control Plot corresponded with a higher percentage of shorter structural sawlogs (Figure 7). The percentage volume of 3.7 metre and 4.3 metre structural sawlogs increased from 2.2% to 3.2%, and 3.2% to 7.5% respectively, whereas the percentage volume of 4.9 metre structural sawlogs declined from 21.8 to 13.5%. The percentage of longer (5.5 and 6.1 metre) structural sawlogs also increased from 61.1% to 67.7%, probably due to less sort 6 salvage/case sawlogs being cut from the butts of the trees. Critically, the use of the simulator's optimiser in the Simulated Plot did not appear to result in an unacceptable change to the sawlog length mix. In addition, the percentage volume of chiplog also declined from 6.5% to 3.9%.

Figure 7: Comparison of yields (cumulative %)



The predicted yield output by product from the Pre-harvest Inventory analysis bore little resemblance to the other two, with greater proportions of low value products and 4.9 and 5.5 metre sawlogs.

3.4.3 Value Recovery Analysis

COMPARISON OF OVERALL VALUE RECOVERY

A comparison of value recovery between the Control Plot, the Simulated Plot and the Pre-harvest Inventory (Table 9) showed that using the optimiser (Simulated Plot) had a small positive impact on the volume of merchantable wood recovered and the unit value of that wood when compared with the result from the actual harvest without using the harvester's OBC and optimiser (Control Plot). Again, both were substantially better than the Pre-harvest Inventory.

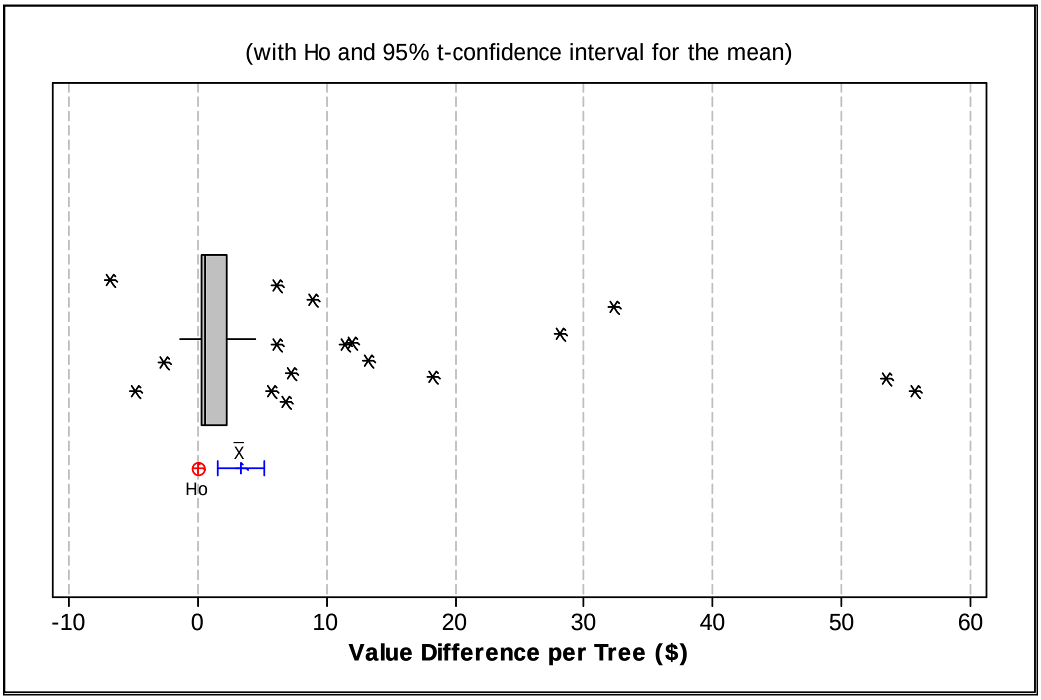
Table 9: Comparison of overall value recovery

	Control Plot	Simulated Plot	Pre-harvest Inventory
Total Production (m^3)	216.3	218.6	201.9
Total Value ($)	$10,272.28	$10,598.37	$8,872.29
Unit Value ($/$m^3$)	$47.48	$48.47	$43.94

COMPARISON OF THE DIFFERENCE IN VALUE RECOVERY BETWEEN DATASETS

Paired t-tests of the mean difference in value recovery between the Control Plot and Simulated Plot datasets over 98 trees [16] indicated that there was a small but significant improvement in value recovery in the Simulated Plot (α=0.05) (Figure 8). This improvement was estimated to be $3.33 per tree (3.2%) with the 95% confidence limit of the mean difference being $1.50 per tree (1.4%) to $5.15 per tree (4.9%).

Figure 8: Boxplot showing the result of the paired t-test value recovery difference by tree (Simulated Plot less Control Plot)



A paired t-test of the difference in value recovery between the Pre-harvest Inventory and Simulated Plot datasets indicated the large and significant improvement in value recovery in the Simulated Plot over the benchmark Pre-harvest Inventory (α=0.05) (Figure 9). This improvement was estimated to be $20.34 per tree (23.5%) with the 95% confidence limit of the mean difference being $16.38 per tree (18.7%) to $24.29 per tree (27.7%).

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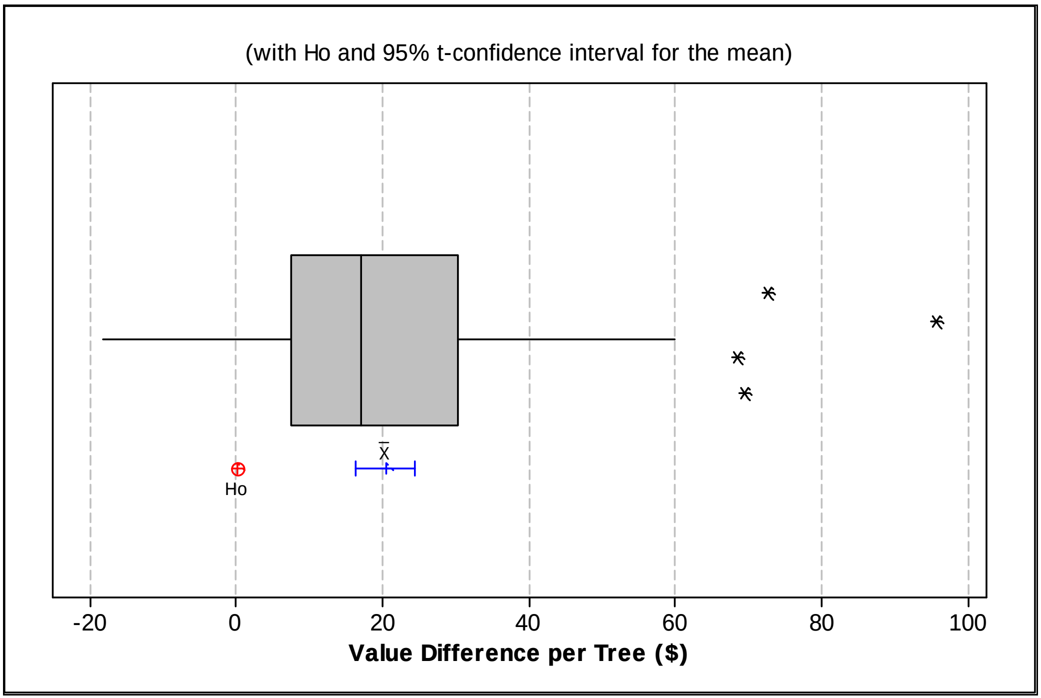
[16] 2 trees from the Control Plot had incomplete volume data by log to accurately determine true value recovery.

Figure 9: Boxplot of paired t-test value difference result by tree (Simulated Plot less Pre-harvest Inventory)



It was also interesting to note that in comparing the two datasets that for a few trees the length of the first log cut determined which option (optimised or non-optimised) provided the best value recovered by tree. If a shorter 4.9 m structural sawlog was cut instead of a longer 6.1 m structural sawlog, the value recovered from the whole tree was always greater. Further examination revealed this was because the % price difference between small end diameter under-bark (SEDUB) classes on the estimated stumpage price diameter curve for structural sawlogs was not the same across all SEDUB classes. In particular, there was a price jump for logs with an SEDUB<38 cm to logs with and SEDUB>38 cm (circled in Figure 10). For these particular trees, if the first log was a 4.9 m structural sawlog it had a SEDUB>38 cm and it attracted the higher stumpage price. If instead the first log was a 6.1 m structural sawlog it had a SEDUB<38 cm due to the taper of the tree and it attracted the lower price. However, the value of the extra volume in the longer 6.1 m sawlog did not outweigh higher price gained for the shorter 4.9 m sawlog when the value of the rest of the products cut from the tree were accounted for.

Figure 10: Estimated stumpage price and % price difference between diameter classes used to determine value recovered

3.5 Potential Value Added

The potential value that could be added to the forest resource through the use of in-forest optimisation is in two parts; harvesting cost savings through more productive operations, and an increase in the average stumpage revenue of the aggregate of products produced [17].

3.5.1 Harvest cost savings

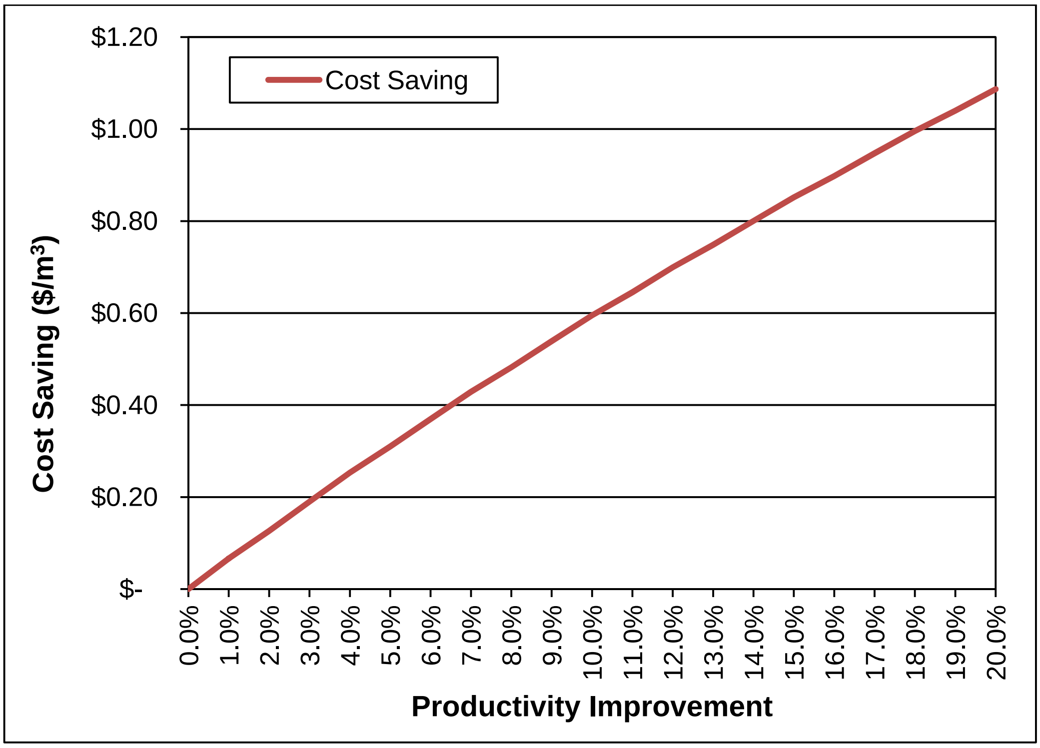
Using the CRC for Forestry's machine costing spreadsheet as a basis for a cost model for a harvest operation with one harvester and two forwarders, the costs associated with the harvesting and extraction operations in the study decreased by $0.55/m^3 (8.5%) [18] due to the improvement in the productivity of the harvester by 9.3% (as shown in section 3.3.3).

A sensitivity analysis of the harvesting cost model showed that harvest and extraction costs would decrease by ~5.4 cents for every 1.0% increase in the harvester's productivity (Figure 11).

[17] The cost and revenue information provided in this report is indicative only, being based on models. It is likely that operational constraints and/or costs may become apparent that are difficult to foresee or quantify and actual costs may vary from the model on a case by case basis

[18] Cost model excludes any allowance for a contractor overheads or margins.

Figure 11: Modelled cost savings with % improvement in the harvester's productivity



3.5.2 Stumpage revenue increase

As indicated in Table 9, (section 3.4.3), the use of the simulator's optimiser in the Simulated Plot dataset served to increase the average stumpage revenue of the aggregate of products produced by $0.99/m^3 (2.1%).

4 DISCUSSION

The results of the Optimisation Study indicated that optimiser technology, when implemented appropriately, could improve the productivity of harvesting operations and deliver an increase in recovered value from the forest. Key to the success of the study, and to ensure the benefits of implementing the technology are captured, was the creation of a simple wood quality code system. Operators used the system to inform the optimiser of the quality of the stem piece to be cut next so it could then suggest the most appropriate products to cut subject to the actual and predicted physical dimensions of the tree.

In this study the productivity improvement of the harvester when using the optimiser was surprisingly large (9.3% for the mean tree size). It remains to be seen if the improvement shown in the study could be maintained over the longer term, but the result certainly indicates significant potential for improvement. An important factor in the productivity improvement is believed to be a decrease in the operator's decision-making time for each log cut because as soon as the saw hit home after every cross-cut the harvester's OBC would have engaged the feed-rollers to move to the next log length as suggested by the optimiser. On the Control Plot the OBC would have waited for the operator to decide on the next log length to be cut before the feed rollers were engaged.

The value recovery improvement from using the simulator's optimiser was modest. This was not unexpected, but encouragingly it also maintained an acceptable log length mix output. Closer examination of the differences between the Control and Simulated Plot datasets, tree by tree and log by log, would seem to indicate that much of value advantage gained by the simulator's optimiser was through its ability to measure the large end diameter over-bark (LEDOB) of the first log cut from the butt of each tree. The accurate measurement and identification of butt logs with a LEDOB < 55 cm, meant that fewer sort 6 salvage/case sawlogs were cut in favour of higher value structural sawlogs leading to large improvement in value recovery in the larger tree sizes (>2.5 m^3/tree).

There were no 5.5 m lengths of HPP Sawlog cut in the Control Plot, whereas they were in the Optimised Plot and Simulated Plot. This may also have contributed to the value recovery improvement as the optimiser had the extra length option available to ensure maximum utilisation of the available sawlog quality volume of each tree. It also highlights the advantage of the optimiser in being able to have many lengths programmed into the apt file and not be limited by the number of available buttons on the harvester's controllers.

As noted in the results the potential for improvement in value recovery was dependent on the length of the first log cut and whether its SEDUB was greater or less than the threshold 38 cm where there was a proportional leap in value. Hence, it is thought that if the apt file could be programmed to better reflect these varying stumpage price differences between diameter classes, the harvester's optimiser could possibly exploit these price differentials, leading to greater value recovery from the forest. A possible next step for research would be to test this hypothesis.

Interestingly, as evidenced by the Control Plot value recovery model and paired t-tests between the Control Plot and Pre-harvest Inventory datasets, the harvest operator also comfortably recovered more value than the benchmark Pre-harvest Inventory value model anticipated without the aid of the harvester's OBC and optimiser. If this same result is reflected in areas other than the study site, it would suggest major problems with the CRUISER tree descriptions, the volume calculation, the cutting strategy or the cutting simulation algorithm used in the analysis of the Pre-harvest Inventory to estimate forest value, and is of some concern.

5 TAKE HOME MESSAGES

The optimisation study showed that the technology could improve the productivity of harvesting operations and deliver an increase in recovered value from the forest.

Key to the success of the study, and the implementation of in-forest optimisation generally, was that the technology was accompanied by a simple wood quality code system that operators could use to inform the optimiser of the quality of the stem piece to be cut next so it could then suggest the most appropriate products to cut subject to the actual and predicted physical dimensions of the tree.

The regression models indicated a modelled productivity increase of 9.3% for the mean average 'normal tree' size when using the optimiser. An important component of this increase is believed to be due to a reduction in the operator's decision-making time for each log cut. This equated to a modelled decrease in the costs of harvesting and extraction operations of ~$0.55/m^3$ or 8.5%.

Using the optimiser indicated a small but significant improvement of 3.2% in value recovery. This equated to an increase of ~$0.99/m^3$ or 2.1% in the average stumpage revenue of the aggregate of products produced.

Harvesting with or without the harvester's OBC and optimiser, comfortably recovered more value than the benchmark Pre-harvest Inventory anticipated. If this issue is more widespread it suggests that there are some major problems with derivation of the Pre-harvest Inventory estimates of forest value.

6 ACKNOWLEDGEMENTS

This project was supported by FNSW and Mangan Logging.

The CRC would like to acknowledge Darren Pointon and Michael Mangan of Mangan Logging, and staff at Forests NSW Bathurst Office for their assistance with this project.

7 MORE INFORMATION

CRC for Forestry website:

http://www.crcforestry.com.au/research/programme-three/index.html

Project scientist Damian Walsh: damianw@unimelb.edu.au

8 APPENDIX 1

8.1 Definitions of Time Elements

8.1.1 Harvesting phase

Felling - Starts when harvesting head clamps onto the base of the tree, immediately prior to the felling cut, and any machine movement ceases, and ends when feed rollers are activated or the tree touches the ground and is in a horizontal position and/or the first bucking cut is made to reset the harvesters length measurement (whichever occurs first).

Processing - Starts when feed rollers are activated, or the tree is in a horizontal position, or the first bucking cut is made to reset the harvester's length measurement (whichever occurs first) and ends when the bucking cut on the last log is made and the log is dropped on the extraction track pile.

The processing element for each log product will start when:

- For the first log - when the feed rollers are activated or the first bucking cut is made.
- For subsequent logs - when the bucking of the previous log product (or waste) is completed.

The element for each log product will end when bucking of the log is completed.

Stacking/Bunching - Starts when the harvester's boom commences a swing to any processed log product, (including any moving to retrieve, move or 'pile' on the extraction track any processed logs), and ends when the machine starts to perform some other activity.

Moving/Positioning - Starts when wheels or tracks begin to rotate and/or the harvester's boom begins its swing towards the next tree and ends when the harvesting head clamps onto the base of the next tree and/or the machine starts to perform some other activity.

Brushing/Clearing - Any interruption to the previous time elements to remove non-merchantable trees or clear processing debris/slash or undergrowth.

Travel – The time taken to turn the machine around to start a new row (or swath) of trees. Starts when wheels or tracks begin to rotate and ends when the harvesting head clamps onto the base of the next tree and/or the machine movement ceases to perform some other activity.

Delay - Any interruption to the previous time elements. The cause of the delay (eg. operational, personal, mechanical, or study induced) will be recorded.