The Potential of Small Scale Sawmills, milling Radiata Pine: A Case study of North Otago Sawmilling Ltd

Bachelor of Forestry Engineering

Honours Project

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1. EXSECUTAVE SUMMARY

The study was done to provide understanding and insight into the productivity and the economic viability of a small scale sawmilling operation milling Radiata pine in New Zealand. Radiata pine makes up 90% of NZ plantation timber (Forest Owners Assocation , 2016).The view of the New Zealand Institute of Economic Research is that portable sawmills are unlikely to mill any significant volume of Radiata Pine due to the relatively high cost of production compared to large mills, (NZIER, 2017). However, there has been no studies conducted in N.Z. on milling Radiata commercially with a small sawmilling operation, hence the reason for this study - to fill a knowledge gap.

A sawmill was studied that had a Wood-Mizer LT70 Super Hydraulic (band saw mill) as a head rig, and an edger linked by a conveyor belt and green chain. To see how run size (volume in number of logs processed in a batch) affects productivity, a gross time study was done on the primary break down of the log, also the time to edge the slabs was recorded to determine the total processing time of each run. A work sampling time study was done to see how each of the 4 workers spent their time producing sawn timber, and to look for potential improvements in productivity of the whole system. A discounted cash flow analyses was also done to determine the potential return on investment for this type of mill set up.

The main results from the gross time study were that the sawmill processed 19 m^3 of log infeed per day on average over the 4 day study this equates to 11.8 m^3 of green sawn timber per day with the sawmills average conversion ratio of 62%. The average productivity for a run was 2.62 m^3/hr (1.62 m^3 green sawn timber) but it varied between 2.17 m^3/hr to 3.03 m^3/hr of log infeed volume. It was found that as batch volume increased productivity also increased. This was because the time to process a run on the edger did not significantly increase with a larger run volume, resulting in higher productivity by producing more timber in a similar time. The range of data is relatively small and there will be a point were productivity does not increase due to some limit in the systems' capacity.

The sampling time study found that out of the whole operation of 4 workers, 10.6% of the time was spent on waste disposal, 3.6% spent on waiting to put finished timber away. Assuming these times can be eliminated through new equipment or management it would lead to an extra 1.8 m^3 sawn timber output per day.

The profitability of a small scale sawmilling operation milling Radiata Pine comes down to contract cutting rate, productivity/production and cost of the operation. The contract cutting rate without lending that made the required rate of return of 20% was \$113/m^3 and fire wood sale price of \$25/m^3. The production of the sawn timber is 2,725 m^3/year and 1,317 m^3/year of fire wood. The cost of production sawn timber was \$93/m^3 and the cost of producing fire wood was approximately \$16/m^3. All these factors come together to make the small scale sawmilling a viable economic investment.

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2. INTRODUCTION

Portable Sawmills have a number of advantages and disadvantages compared to a large fixed sawmills. An advantage of a small portable sawmill is that they can mill up speciality timber, because they can offset high production cost due to low production rate by producing high value sawn boards. The amount of capital expenditure required to set up a small portable mill is significantly lower than a large industrial mill. More employment is needed per cubic meter produced than will a large automated mill. The recovery rate tends to be higher with a small sawmill (Smorfitt, 2013). The recovery rate is determined on the skill of the operator given set standard of logs. Some of the disadvantages are the higher cost of production, due to lower production rate (productivity) and more labour needed per m^3 of sawn timber (Smorfitt, 2013).

Production of portable mills depends significantly on the type of mill used. Exotic conifers and eucalypts species are about $0.1m^3$/hr for a chainsaw mill, $0.84m^3$/hr for single blade Lucas mills (Venn, 2004), and $2.5m^3$/hr for twin circular saw sawmills (Stewart, 1998). For a Wood- Mizer LT70 super Hydraulic band saw mill operating in Romania production was 1.5 m^3/ hr (Craciun, 2016). Other factors affecting production are number of people used, level of systemization, layout, and mechanisation.

There are a number of small saw milling businesses in NZ. These business mill speciality timbers like poplar, oak, Eucalyptus, Acacia, Macrocarpa and more (Fairweather, 2016). These business tend to produce high value products to offset the high cost of production associated with low production. These timber species are the minority of New Zealand's plantation resource, with 90% of the resource being Radiata Pine (Forest Owners Assocation , 2016). There has been feasibility studies of milling of Eucalyptus in NZ; however, the operation is not as yet in commercial production (Satchell, 2015). The view of the New Zealand Institute of Economic Research is that portable sawmills are unlikely to mill any significant volume of Radiata Pine because of the relatively high cost of production compared to large mills, this also depends on regional competition, location, accessibility of logs and profit margins required for business (NZIER, 2017). There is very little known about the processing of Radiata with a small sawmilling operation.

The need for a study on small sawmilling operation milling Radiata Pine is evident, because of NZ plantation resource being 90% Radiata pine. There has been no studies done on milling Radiata Pine with a small sawmill. To determine the potential of milling Radiata pine economically the two biggest questions are the cost of operation ($/hr) and the productivity (m^3/hr). The study was conducted on a small sawmilling business milling exclusively pruned Radiata Pine on contract for Great Southern, Oamaru. The operation has been running for more than 20 years. This study will look at the productivity of this milling operation by conducting a gross time study and a work sampling time study of the milling operation and it will look for potential improvements in productivity by doing a sample time study. A discounted cash flow analyses will be done analyses the potential for this type of operation in NZ.

3. LITERATURE REVIEW

There was no literature on milling Radiata pine with small sawmills and only one paper was found that was did a productivity study on a small mill.

There were papers of portable sawmills, these mainly about environmental effect, economics of small mills, and paper discussing the relative merits of them compared fixed large-scale mills (D. B. Smorfitt, 1999).

The contract cutting rate of producing sawn timber in Queensland was $486/m^3 however, this was tropical hard wood which is a lot harder to cut. A sawmilling business in Canterbury charges $140/hour (Fairweather, 2016) as this is for speciality timbers and is a low production operation. A ball park figure for a contract cutting rate from Mr Fairweather was $200/m^3. But the biggest driver for determining the contract cutting rate is the volume of production. The more the mill can produce the lower its fixed costs per meter cubed produced.

A study that was of interest to this project from the productivity side of this study was a fuel reduction operation in America (small coniferous logs between 7 – 25 cm diameters) conducted a study of the productivity of the Economizer saw mill. This mill is fully portable and takes a few hours to set up. It is built specially for processing small diameter logs. First the log is squared up with chipping head rig and then goes through a multi-rip saw (Magagnotti, 2009). The productivity was 0.3 – 2.8 m^3 per working hour with a recovery rate of 50%. Working hours include mill disassembly, relocation and set-up (Magagnotti, 2009).

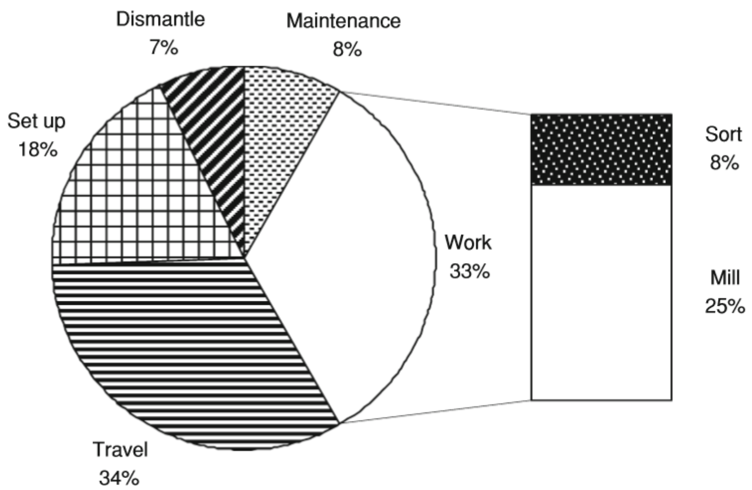

Figure 1:Acivity breakdown (% occurrence/ time) (Magagnotti, 2009)

This shows the amount of time spent doing each task. Figure 1 shows that travel, set up, and dismantle time took 59% of the time showing the clear advantages of having the small mill set in one location or having large volumes to mill at one site.

A relationship between productivity (m^3/h) and small end diameter inside bark (SEDIB) was developed see figure 2

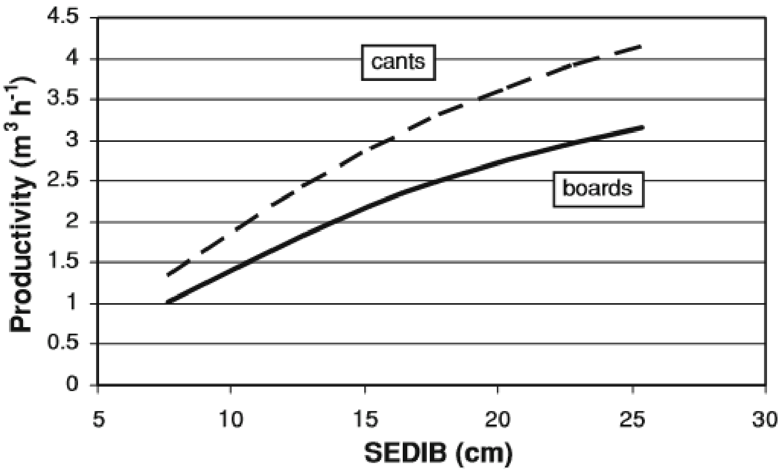

Figure 2: Milling productivity including delays as a function of SEDIB. Note cutting boards thickness was 2.5 cm and log length was 3 m (Magagnotti, 2009).

Looking at figure 2 it is clear to see the productivity is increasing at a decreasing rate. Given that North Otago mill are milling logs will diameter spec of SED 40 cm. So a 40 cm log diameter may less productive or equal to a 30 cm diameter mill. However, the economizer was designed for small logs and the Wood-Mizer band saw mill is used for larger diameter logs so the curve will most likely be different from this mill.

When saw mills are required to increase throughput they often resort to purchasing new machinery in the bottle neck to increase production (Steven, 2008) this is not entirely needed for some quantity of increased throughput. The mill in North Otago will be purchasing a new Wood-Mizar in the hope of increasing productivity weather it does or not remains to be seen.

4. OBJECTIVES

Conduct a Productivity study of a small sawmilling operation, milling pruned Radiata Pine on contract, with a Wood-Mizer LT70 Super Hydraulic for the head rig, and looking for potential improvements in productivity of the whole system.

Sub-objectives:

- Gross time study of the primary break down of log with Wood-Mizer LT70 Super Hydraulic for looking at how batch/run size effects productivity.
- Sampling time study of whole operation to see percentage of time spent on each task to produce sawn timber.

- Provide background to the North Otago Sawmilling Ltd operation to put study into context.
- Provide an economic analyses to see small sawmilling potential in NZ with milling Radiata pine.

5. BACKGROUND

This study will be conducted on the productivity of North Otago Sawmilling Ltd. The mill mills pruned Radiata Pine on contract for a Great Southern, Oamaru. The logs are purchased and delivered to the mill by Great Sothern. The green sawn timber is then collected by the customer for drying and processing at their plant facilities. North Otago Sawmilling selectively saw logs to recover the maximum amount of clear wood out of each log. Then the knotty core is also sawn up. North Otago Sawmilling Ltd have to deal with the waste, the slab wood is sold as fire wood, the breast bench sawdust is sold and the sawdust from the Wood-Mizer is given to the meat works.

The mill operates in batches/runs of 3 to 4 logs for approximately 60 minutes accumulating primary broken down logs on an accumulating table, see Figure 3. Then, the Wood-Mizer mill is turned off while these boards are put through the edger this takes approximately 26 minutes. The timber is stacked by grade in packets to be trucked out will the edger is operating.

The mill uses P1 log grade which is SED larger than or equal to 40 cm and length of 4.8 m plus.

5.1 Mill layout

Figure 3 below shows the material flow in the mill with the arrows. The boards are man handled to be stacked onto the accumulating table off the green chain. Waste slabs are taken off the side of the green chain and taken directly to waste slabs pile. Boards are handled onto edger, pushed through, then waste is thrown into waste pile and boards are carried out to the packets of finished timber.

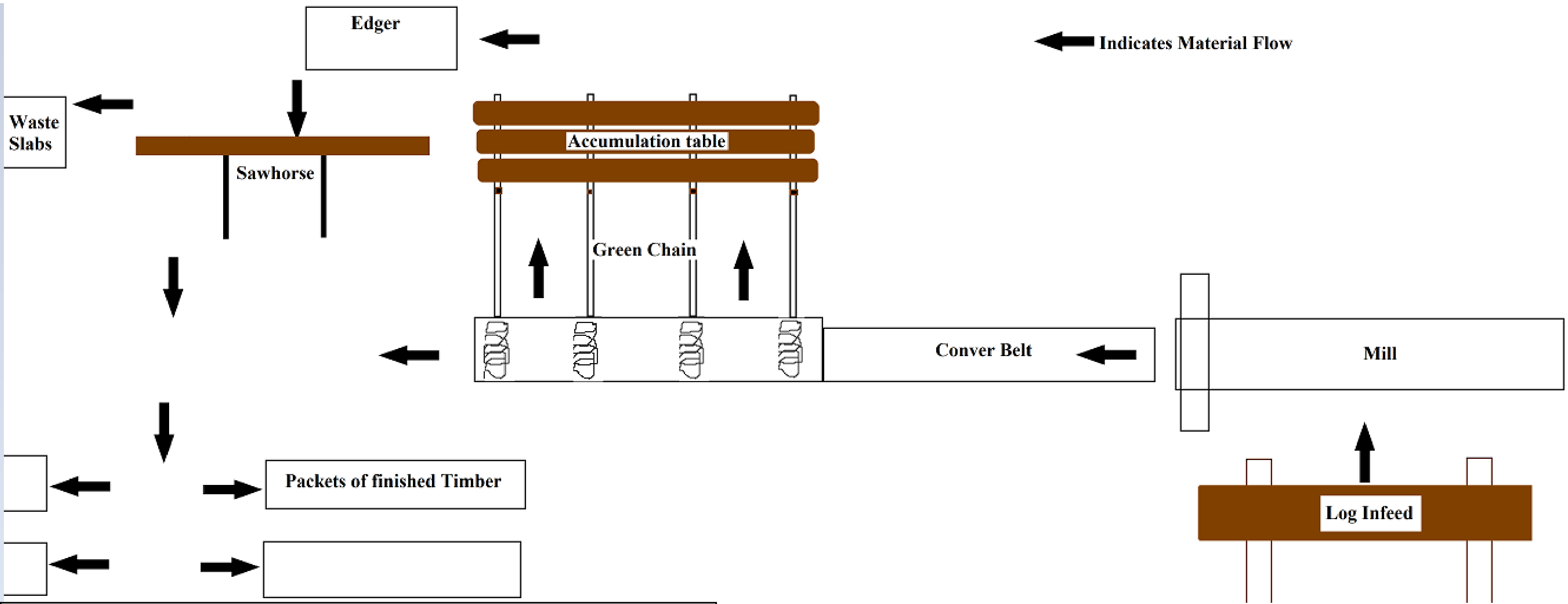

Figure 3: Layout of mill production system and material flow.

5.2 Gross time study of head rig (Wood-Mizer LT70 Hydraulic)

Objective is to determine how batch/run size affects productivity of the head rig per PMH.

PMH is all time of production including delays but excluding the scheduled 2 half hour breaks.

A batch/run is defined by the number of logs that are sawn up before head rig stops and bench saw starts to process the accumulated material.

Primary break down of a log is the process of turning a log into slabs/boards. These boards are then accumulated. The mill will stop and the edger is started to take rough edges off the boards and cut them to size.

Primary break down time of each log volume defined as when mill moves hydraulic loader to the next time mill moves hydraulic loader to pick up next log.

The logs SED, LED and length were measured to calculate volume using the Smailian Log volume equation (Ministry of Forests, Lands and NRO, 2011):

$$Log\ volume = \left(\frac{\left(\frac{SED}{2}\right)^2}{2} + \frac{\left(\frac{LED}{2}\right)^2}{2} \right) x\ Length$$

The primary breakdown time of each log will be measured individually. The times of individual logs in the batch will be added up to get the total primary breakdown time for that run. To get the sawn timber output of production use a conversion ratio of sawn timber to log volume. Multiply this conversion factor by the infeed log volume for the batch. This gives the sawn timber volume produced.

5.3 Work sampling of tasks preformed for productivity of whole system

This time study will give the amount of time spent on each task performed by each of the four workers. This gives an indication of how the time is used to produce the sawn timber (m^3/PMH). It also identifies the use of the assets of the mill and potentially highlights areas were the mill could improve their systems to reduce time on certain unnecessary tasks. This information will answer the second part of the objective of this study, looking for potential improvements in productivity of the system.

5.3.1 Defined tasks of work sampling time study

- OM = Operating Mill. See Figure 4

Figure 4: Showing the operating Wood-Mizer mill (LT70 Super Hydraulic).

- AM = Assisting Miller to prevent log from warping.
- MSTP = Moving Saw Timber Primarily broken down. See Figure 5.

Figure 5: Putting partially processed timber from conveyer belt to the accumulating table.

Figure 6: Moving finished timber from the edger to the packets outside.

- MFT = Moving Finished Timber. This includes taking finished timer from either mill or edger. See Figure 6.
- CE = Cleaning Equipment. This included removing sawdust from inside edger and mill.
- CF = Cleaning Floor e.g. sweeping saw dust
- OE = Operating Edger. This involved two people (Figure 7) the worker on the left pulled the planks through the edger, placed the finished timber on the saw horse, slid unfished boards back to worker on the right, and put the waste wood in a pile behind him. The worker on the right took slabs off the accumulating table, decided what could be saw out of them, adjusted the fence for board, and fed the slabs through. With hand signals the worker on the right would communicate the grade of that board to the people putting away the finished timber.

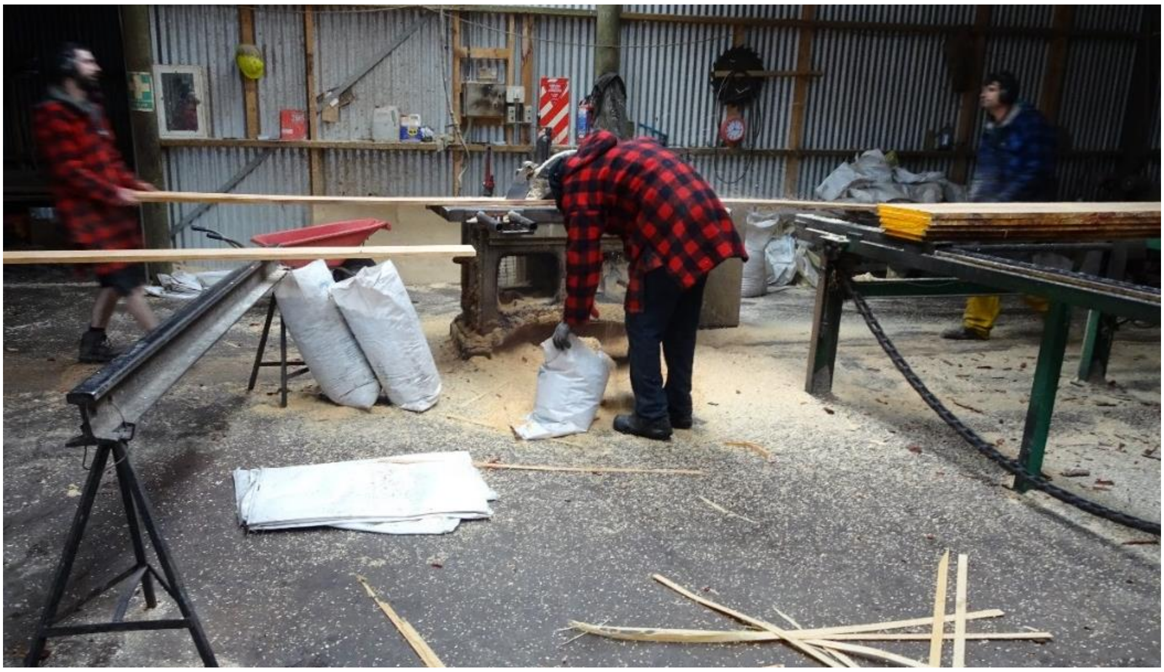

Figure 7: Operating edger (OE) and moving sawdust (MSD).

- MSD= Moving Sawdust. This was putting edger sawdust into bags, carrying them, and sweeping immediate dust for purpose of putting into sacks. See Figure 7 above.
- Waiting. This included waiting at edger sawhorses for timer to put away or waiting to get waste wood of mill.
- MM = Maintance of Machinery. This included blade sharpening, blade swopping, chainsaw maintenance, and chainsaw refuelling. While these activities occurred, production was not delayed.
- PW = Paper Work. This was tallying the timber packets.

Figure 8: Operating the loader.

- OL = Operating Loader. This included loading the mill infeed, moving finished packets of timber, and moving packets of sab wood.
- DM = Delay Mechanical, maintance that stops production.
- DS = Delay Social. This included toilet break, drinking water, smoking, chatting, and checking cell phones.
- DO = Delay Operational, delay that needs to occur for operation to continue. This included dealing with customers who wanted fire wood, taking chainsaw chaps on or off,
- DF = Delivering Fire wood
- FA = Fire wood Activity. This included sawing the slab wood packets into fire wood and loading the truck up.
- CL = Cleaning Logs. See figure bellow

Figure 9: Water blasting logs before milling them.

- MP = Manipulating Packets. This involved counting boards, stacking sawn timber, and tying the packets up. See Figure 10.
- TP = Trimming Packets. This is shown in Figure 10 below, basically docking the timber to length.

Figure 10: Example of trimming packets, manipulating packets, and waste wood that will be moved.

- MWW = Moving Waste Wood. This included picking up packet trimmings (see Figure 10), taking opening slabs off green chain and putting them in the pile, and picking up small pieces off the floor during or after edger had stopped (See Figure 7).

5.4 Conversion ratio for log in to Sawn timber out

The conversion ratio between logs to sawn timber was accessed from North Otago Sawmilling 's customer Great Southern, Oamaru. The conversion ratio is based on the weight of logs delivered to North Otago Sawmilling. The log weight is converted to volume through a weight conversion ratio. The log volume is then divided by the volume of timber that is supplied to Great Southern.

This was calculated every month. The average conversion ratio for the months 2017 to date were used. This was 62% from log to green sawn timber.

6. RESULTS

6.1 Production

The sawmill processed 76 m^3 of log infeed in 4 days. This is 63 logs for 4 days. The first day 10/07/2017 I arrived and started the study at 10am and the mill finished at 2 pm on Friday the 14/07/2017. Edger would start up and process the run of boards left on the accumulating table from the previous day at 7 am and the gates were locked at 5 pm. This occurred every day.

So sawmill processed an average of 19 m^3 of log infeed per day for the duration of the study. Using the conversion ratio supplied be Great Southern, Oamaru of 62% this equates to 11.4 m^3 of green sawn timber production per day.

The Productivity ranged between batches varied from 2.17 m^3/hr to 3.03 m^3/hr infeed log volume. The average productivity was 2.62 m^3/hr log in feed volume.

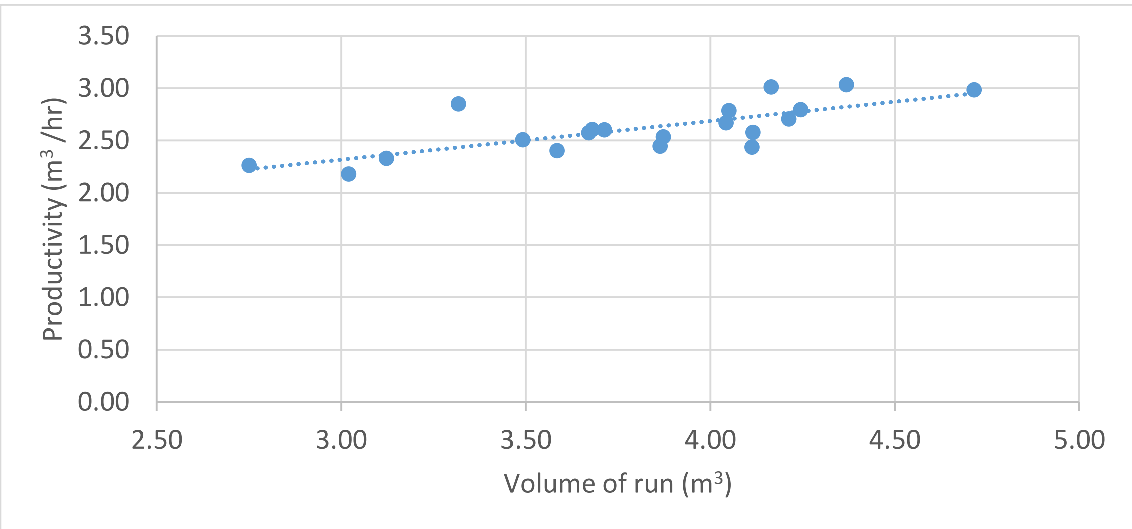

Figure 11: How productivity changes with run volume.

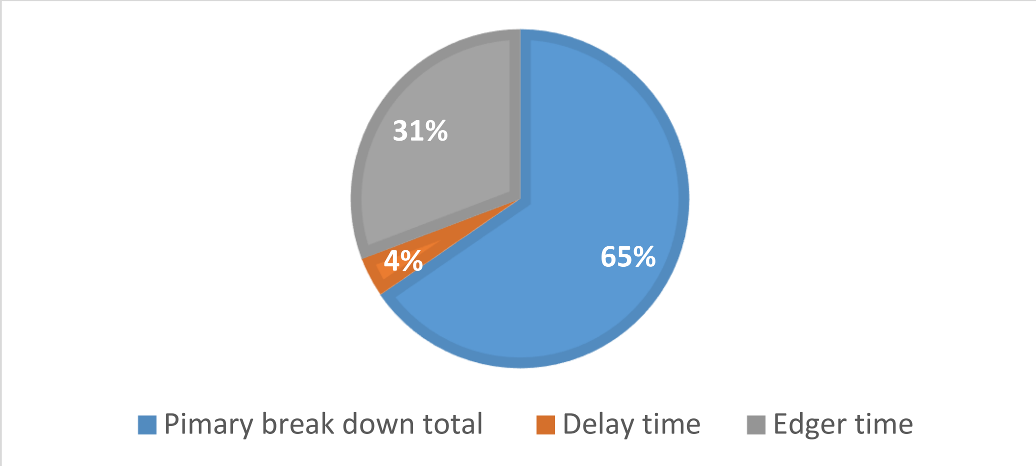

Figure 12: Percentage of day spent on edging, primary break down and delays (PMH) Note excludes scheduled breaks.

6.2 Primary break down of logs

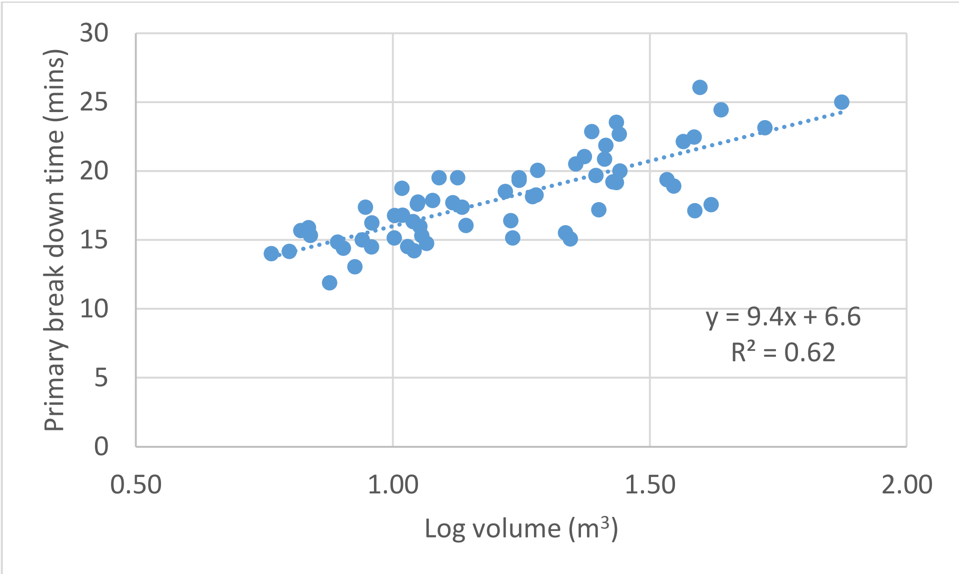

Figure 13: Primary break down of log time against log volume.

Primary break down time of a log increases as volume of log increases shown in Figure 13. This was an expected result. Log volume explains 62% of variation in primary break down time. This relationship has very low P value, so 99.9% sure this relationship is correct.

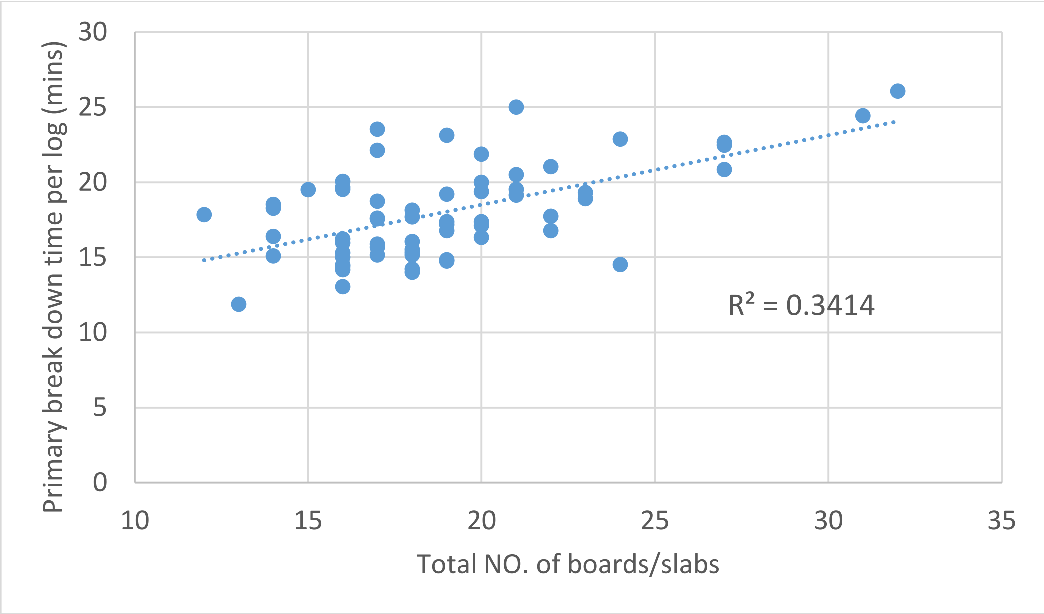

Figure 14: Relationship between primary break down time and total number of boards.

Figure 14 shows that as total number of boards/ slabs increases the primary break down time increases. This relationship is significant ($P < 0.0001$) and explains 34% of the variation of primary break down time with the total number of boards.

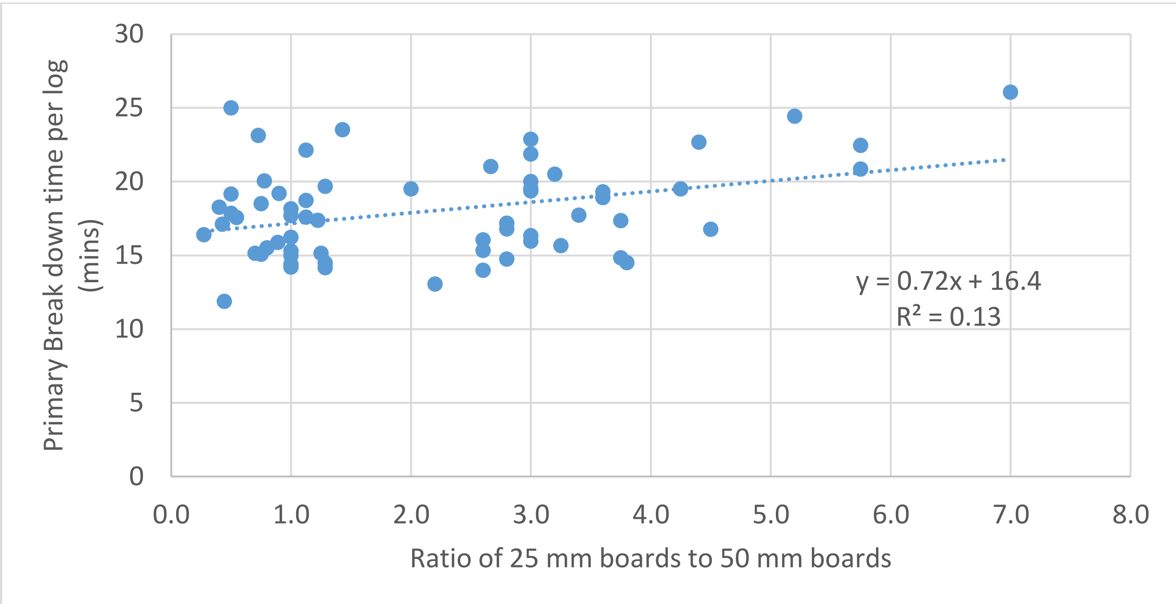

Figure 15: Effect of cutting strategy has on primary break down time for each log.

There was two cutting regimes. They were 50mm thick clears, 25 mm clears and 150 by 50 mm knotty core boards, the cutting strategy then changed to just cutting 25 mm clears, and 150 by 50 mm knotty core boards that went straight from the mill to finished timber packets. The ratio of number 25 mm boards divided by 50 mm boards shows the cutting strategy change. The first strategy cut 50 mm clears this is on the left group of data points shown in Figure 15.

The trend shows that when cutting 50 mm clears the primary break down time decreases (Figure 15). This relationship is significant (P = 0.004) and explains 13 % of the variation in the primary break down time of the log. This relationship was expected because cutting larger volume boards means the time to break down log should decrease.

6.3 Primary break down for a run

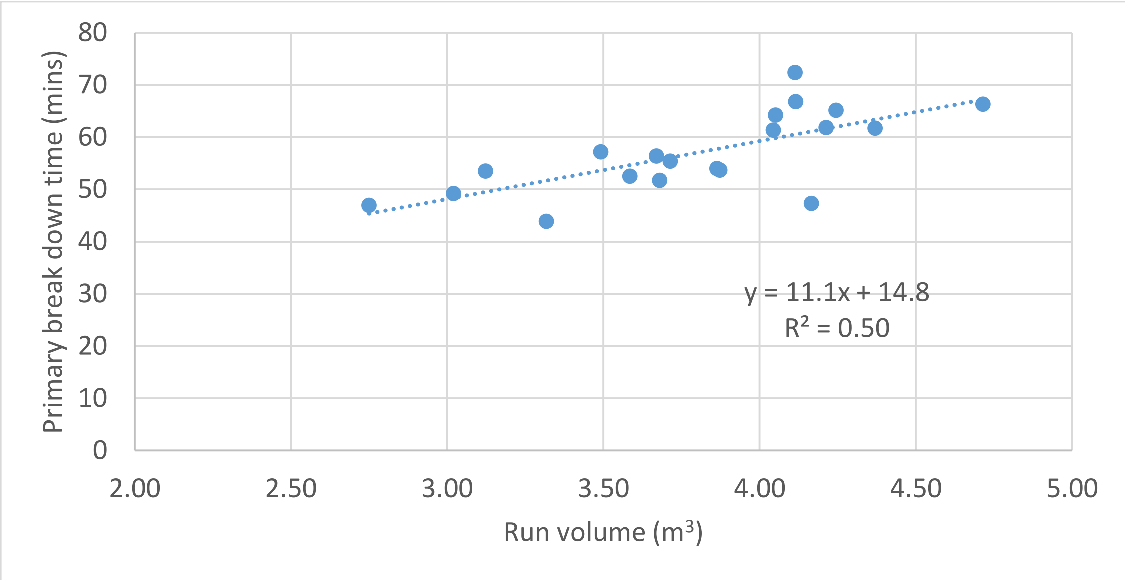

Figure 16: The effect run volume has on primary break down time.

The relationship shown in Figure 16 means that if batch/run size increased, the processing time would increase for the primary break down section. This is expected and has a very low P value, meaning this is a significant relationship.

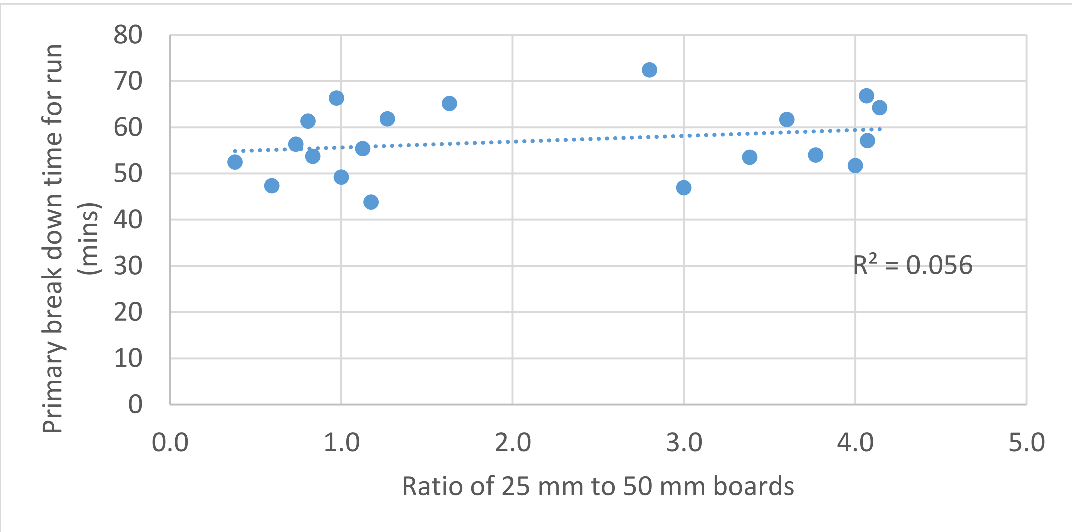

Figure 17: Relationship that cutting strategy has on primary break down time.

Figure 17 shows that the change in cutting strategy only explains 5.6% of the variation of primary break down time (P = 0.32). It is interesting to note that when measuring the primary break down time for the run the change in primary break down time is much less significant with change in cutting strategy than the change that occurred in Figure 15.

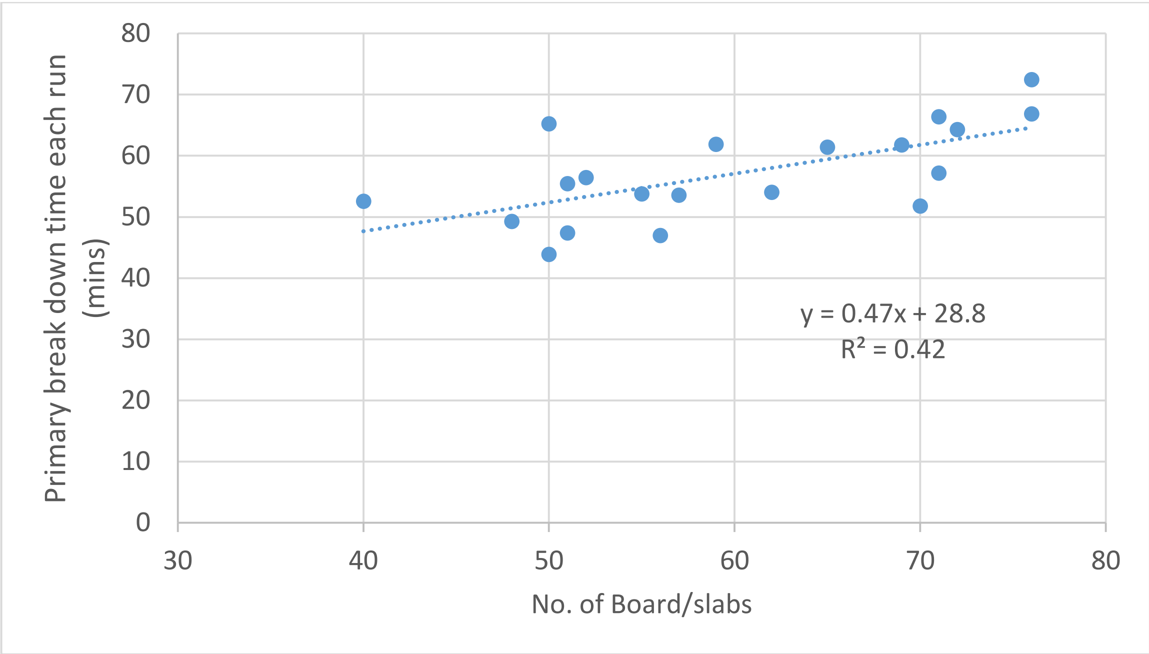

Figure 18: Effect of total number boards/ slabs has on primary break down time.

There is a significant relationship between primary break down time and total number of boards cut, with a P value of 0.002. The total number of boards cut explains more of the variation in the primary break down time than the ratio of 25 mm boards to 50 mm boards.

6.4 Edger time for runs

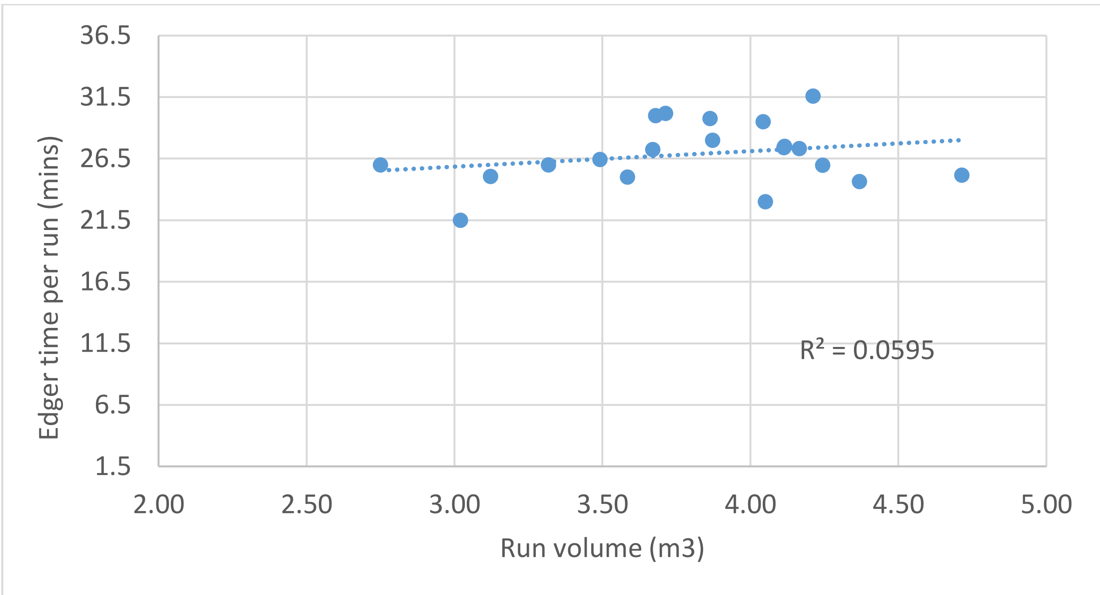

Figure 19: Effect of edger time with changing run volume.

Looking at Figure 19 run volume only explains 8.6% of the edger time variation (P = 0.21). Which according to Figure 19 increasing run volume will have limited effect on edging time for a run. This would mean that overall productivity would increase as amount of volume procced increases. The edging time for the larger run will not be significantly different from a run with a smaller volume. The result being that productivity should increase with bigger run size.

However, the total number of boards handled in each run should be a better indication of the time taken to go through edger than run log volume as edging is about boards/ slab handling. Figure 20 shows that there is no relationship between the number of boards produced and time taken at the edger (P = 0.95).

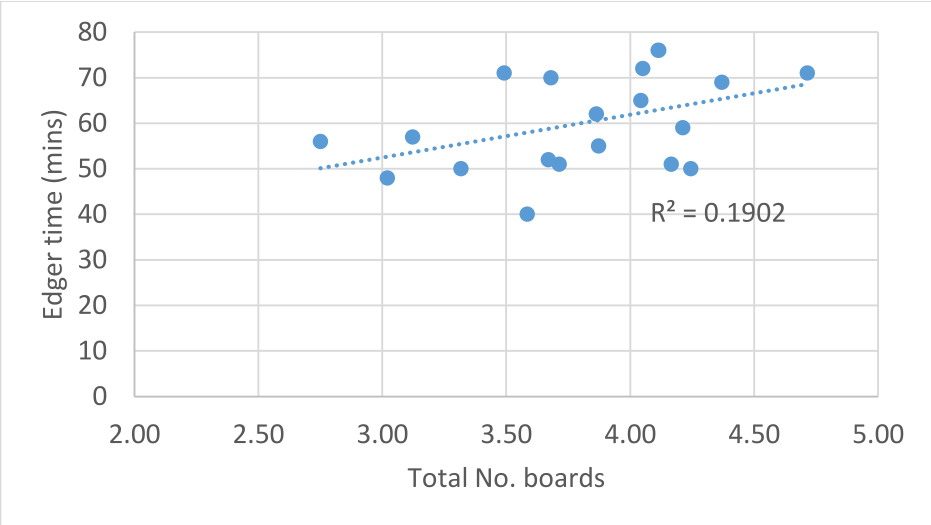

Figure 20: Total number of boards produced effect on edger time.

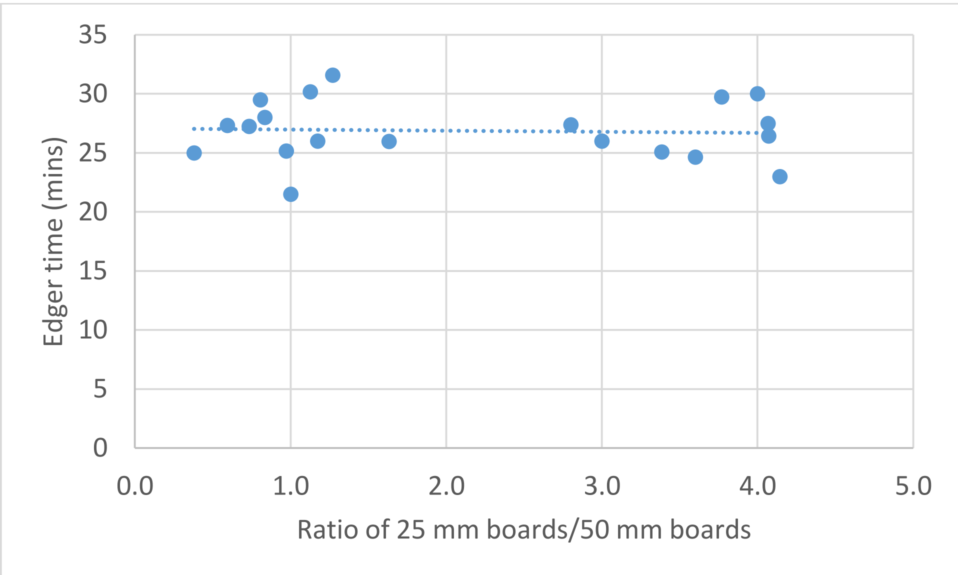

Figure 21: Relationship the ratio of 25 to 50 mm boards have on edger time.

Figure 21 was produced knowing that the cutting strategy changed.

Figure 21 clearly shows that there is no effect on edging time with number of 50 mm boards cut or number of 25 mm boards. The P value is 0.823 indicating no significance.

A proposed hypothesis was that it may take longer to process 50 mm, because of the extra weight the workers have to handle.

6.5 Work sampling study

The reason for conducting a work sampling study was to see how the 4 mill workers spent their time to produce the sawn timber output.

Each worker performed a set range of tasks. For example, worker 1 was the only person to operate loader, deliver fire wood and saw dust. So, to get a better understanding of how productivity could be potentially increased each workers activity record was kept separate. The tasks that a worker did not do were not included in the graphs of how their time was allocated to different tasks, to make graphs easier to read. Also any activity that took less than 1.5% of the sample time for a given worker these activity times were added together to form the ''Other'' activity.

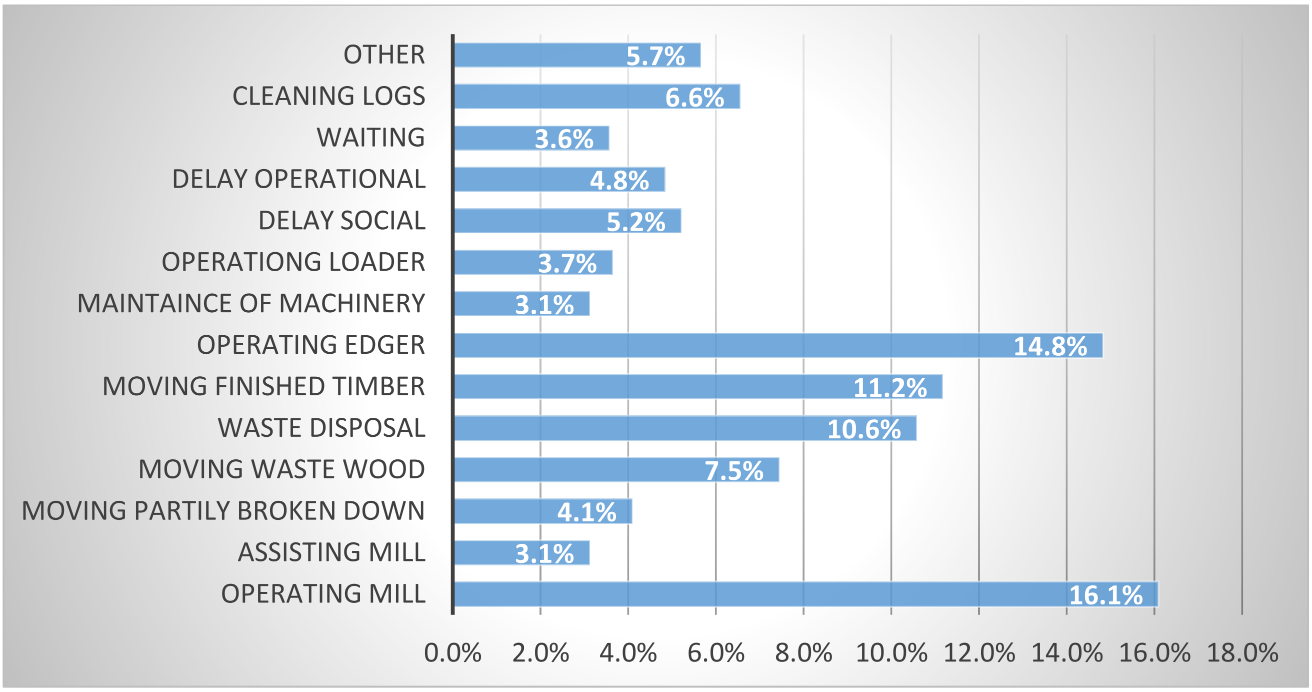

Figure 22: How the combined labour units of operation use their time to produce sawn timber.

10% operation is equal to 40% of 1 workers time.

Looking at Figure 22 the most important tasks are operating the mill and edger.

The mill spent 3.1 % of the operation assisting the miller this mainly consisted of providing weight to prevent the remaining timber from warping this can be replaced by hydraulic clamps that prevent the log from warping.

Looking at Figure 22 it is interesting to note that waste disposal, which included putting saw dust into feed sacks, delivering saw dust or fire wood, and fire wood activity, took 10.6% of time spent over 4 days averaged for 4 workers. So effectively 1 worker spends 40% of his time on waste disposal. That is almost the same amount of time spent as putting finished timber away.

Figure 23: Fire wood activity of loading the truck up will cut slab wood.

Amount of time spent waiting is 3.3 % of whole operation which is the equivalent of 13.2% if this time was allocated to a single worker. Most of the time waiting time takes place during the process of putting finished timber away.

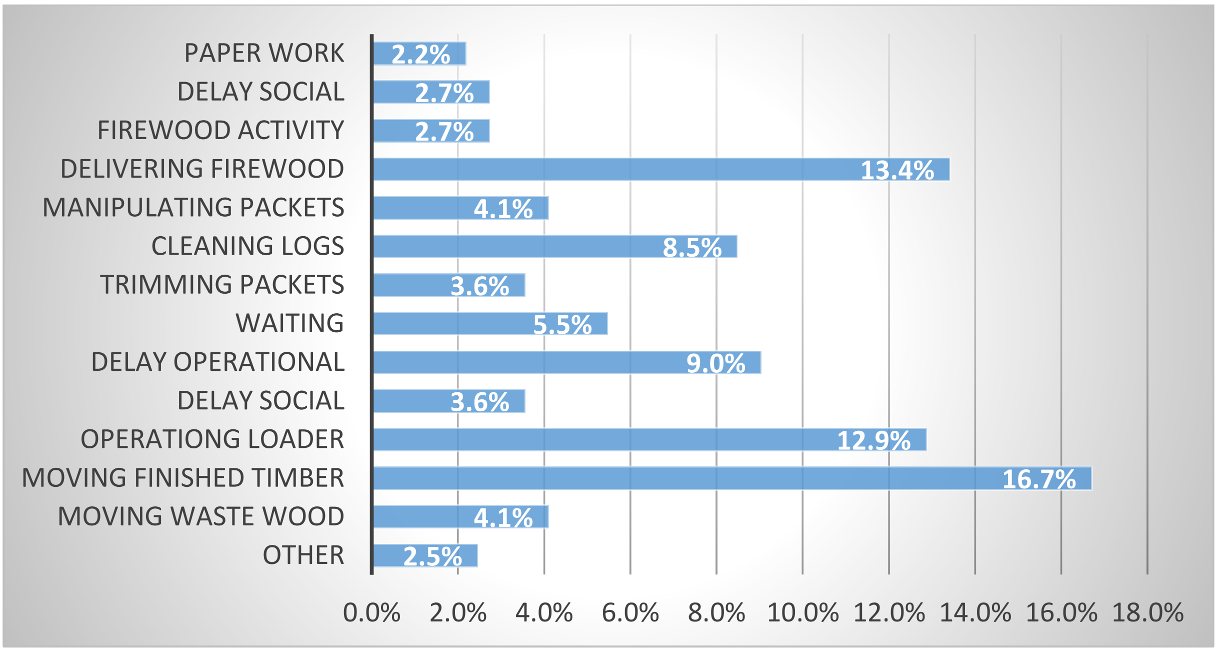

Figure 24: How worker 1 spends his time to produce sawn timber.

Worker 1 spends 13.4% of his time delivering firewood. This task is not producing sawn timber which is the primary product for the mill. With delivering firewood and sawdust included in this time, dealing with waste is 18.8% of worker 1's time. If worker 1 was employed at $25/h this means in one week of 47 hours North Otago Sawmilling spend $220/week on waste disposal. This direct expense would be covered by the sale of firewood but the loss in production of sawn timber may have a greater expense than revenue generated with firewood.

In Figure 24 W1 spends 5.5% of his time waiting at the edger to put finished timber away. This is a ¼ of the time spent putting finished timber away and waiting combined. This waiting time is spent at the sawhorses waiting for material to come off the edger see Figure 25 below.

Figure 25: Worker collecting wood from sawhorses moving finished timber.

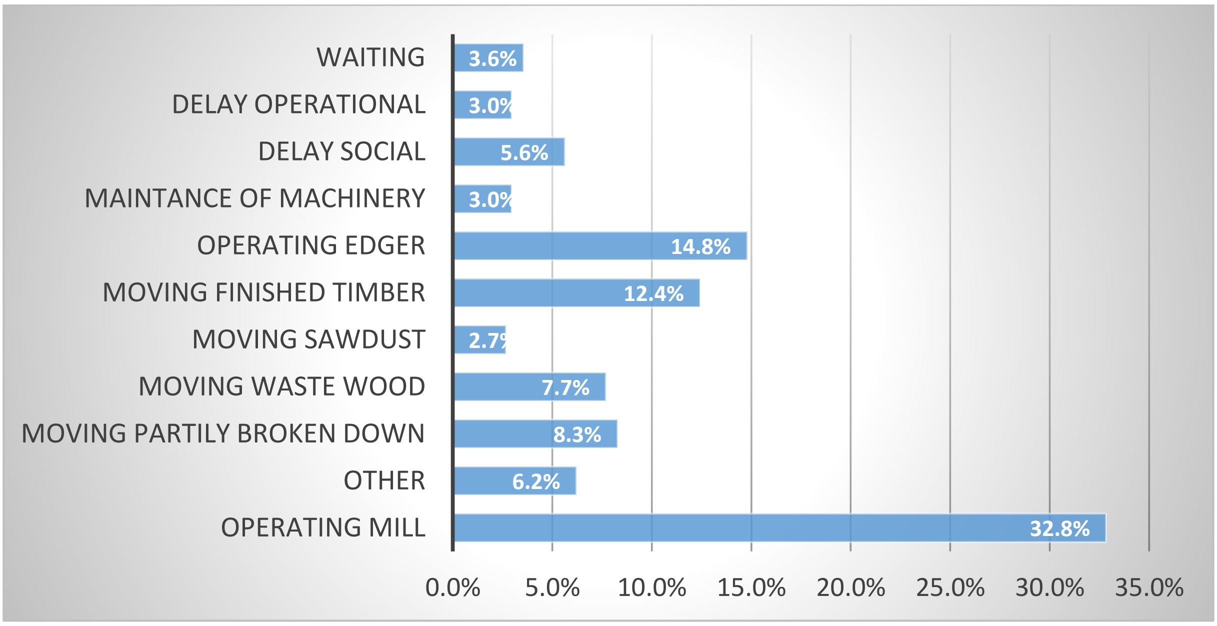

Figure 26: Worker 2 work sample on producing sawn timber.

Worker 2's primary tasks were operating the mill, receiving boards coming through edger, moving finished timber, waste slab wood, and stacking the partially broken down timber on the accumulating table.

The amount of time spent waiting for finished timber to come of the edger a ¼ of the time spent putting away finished timber and waiting combined.

W2 is spending 5.2% of his time of social delays involving checking phone, smoking, toilet and chatting. This does not produce timber but is important part of keeping worker productivity up by effectively having small breaks from his work. The best way to improve productivity is reduce non-productive time utilisation such as waiting for material to come off edger to put away, not social delays as worker happiness will go down resulting in less productivity if the social delays were to be minimised.

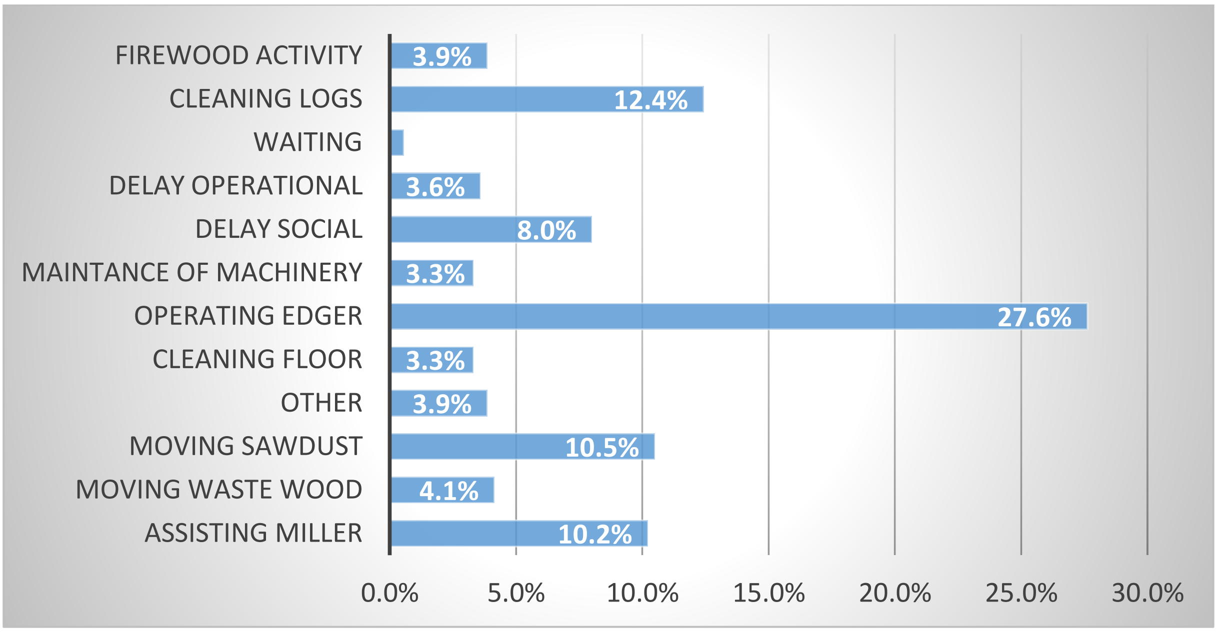

Figure 27: worker 3 work sample study in producing timber.

Worker 3's main task was putting partly broken down boards through the edger. This takes 27.6% of his time. He was responsible for deciding the grade of board and what could be cut out of each particular slab that came off the accumulating table. This is a very important part of the recovery process from the log to get sawn timber.

W3 spends 10.5% of his time sweeping and shovelling edger saw dust into feed sacks and carrying them to storage location. This time spent moving sawdust is something that an extractor system could do. This would free up 4.7 hours per week for W3 and this time could be spent operating the edger instead. Which would be a more efficient use of time.

Note that W3 waiting time is very low as he does not put finished timber away.

10.2% of time W3 was assisting the miller by either rolling logs onto mill or providing weight to stop the core wood warping as the core of the log is sawn up. Preventing the log from warping could be achieved with hydraulics system of holding log.

W3 also spends 3.9% of the time on fire wood activity which involves sawing up slab wood or loading it onto the back of the truck. This is also time spent on not producing sawn timber.

W3 spends 8% of his time on social delays. The potential reason for worker 3 having more social delays than say worker 2 or 4 is because W2 and W3 can have a mini break to while saw is going through log when operating mill. Whereas worker 3 does not have this time, so needs to take breaks not producing anything. Also W3's cigarettes had to be hand rolled taking more time then say worker 4 who had an electronic cigarette. W2 also rolled his own cigarettes resulting in higher social delay time. W1 did not smoke but he had that break time in delivering fire wood.

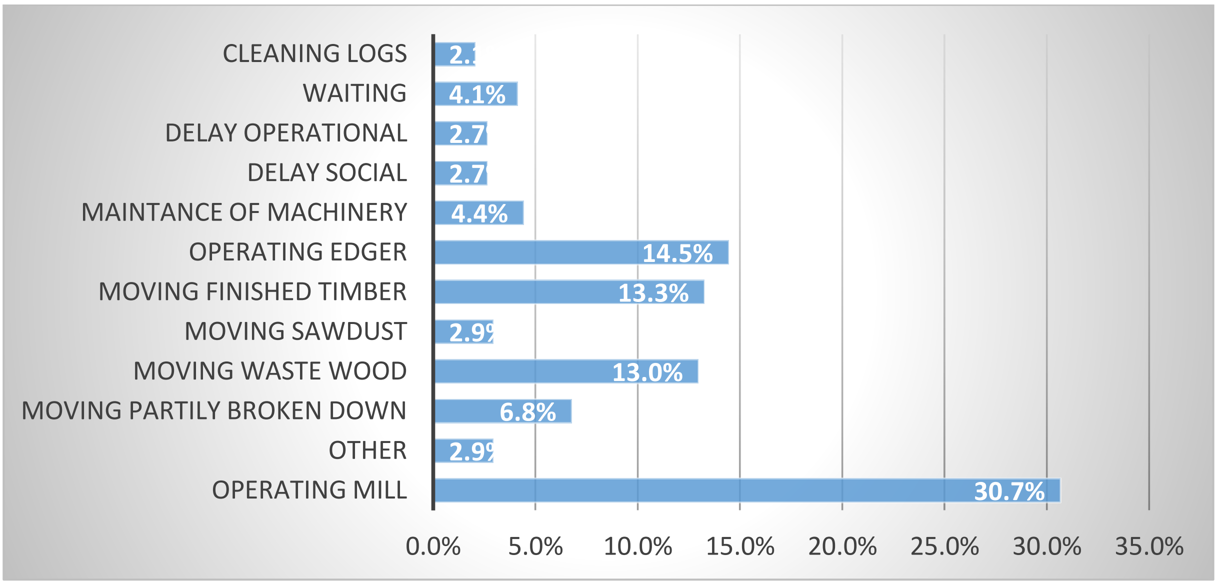

Figure 28: Worker 4 sample work time on producing sawn timber.

The amount of time spent of putting finished timber was 12.2% of the time (Figure 28). The amount of time spent waiting was 3.8%. This means that waiting time is just under a third of the time putting timber away.

Worker 4 primary tasks were operating the mill, pulling the boards through the edger, moving finished timber, and moving waste wood.

6.6 Predicting Productivity of the operation

An equation was made to predict the productivity of the mill with a given run volume. This was done to show how changing run size will change productivity.

To calculate the productivity of the mill, the run volume was divided by the total run time. The total run time is made out of two components primary break down time and edger time. The regression equation was formed to calculated total run time.

The primary break down time depends on the quality of log, cutting strategy, log volume, operator, and other factors. In the study SED, LED and Length were recorded for each log, these variables were used to calculate log volume. Then each log volume was summed up for logs in that run to get run volume this was the independent variable used to predict primary break down time.

Another possible independent variable is the mill operators. The two operators alternated between runs. The difference between the average primary break down times for 16 runs for the two operators was 1.2 minutes. So clearly they had very similar productivity so no significance in predicting the primary break down time.

The regression analyses found:

$$Primary\ break\ down\ time\ per\ run\ =\ 14.8\ +\ 11.1\ Run\ volume\ \pm 5.5$$

The error term is the residual standard error which is the 'average' distance between the observed point and the regression line. The true error of the regression equation is less at the centre of mass of the data and error increase as predicted values move away from the centre of mass of the data points. This means that to make a prediction with a run volume of 4.7m^3 or greater will lead to a greater error in the prediction than the error presented in primary break down equation shown above.

The regression line had a R^2 value of 50%, meaning that run volume only explains 50% of the variation found in the primary break down time. The error term in the regression equation explains the other 50% of variation. Being able to explain 50% of the variation in time with one variable is a good result in a complex system. Primary break down time depends on the knotty core of the log, the boards required by the customer and the growth stresses within log. The P value was less than 0.0005 so a significant relationship.

To see if the main liner regression assumption were met there are some required tests; the regression equation is linear, the data is relevant to the problem of finding primary break down time as data taken from this mill. There are three tests on the residuals to see if the regression is a good fit, firstly to check independence of the residuals. This was done using the Durbin Watson test (Minitab Inc, 2017), the test shows if the errors from the fitted regression line to the observed values are correlated. If the errors are correlated the linear regression may appear to explain more variance than it really does. Using Minitab and tables (Minitab Inc, 2017) that accounted for sample size, number of terms and Durbin Watson (D_u, D_L) upper and lower bounds were found with 20 run volumes, two intercepts and having a D of 1.9, showed there was no correlation between errors as the D_u was 1.4. This test has significance (P = 0.05).

Secondly equal variance of the residuals is achieved. This is shown by the errors from fitted values to the actual data points. Looking at the Figure 29 it shows that the variance of the residuals is relatively consistent and equally distributed along the regression line.

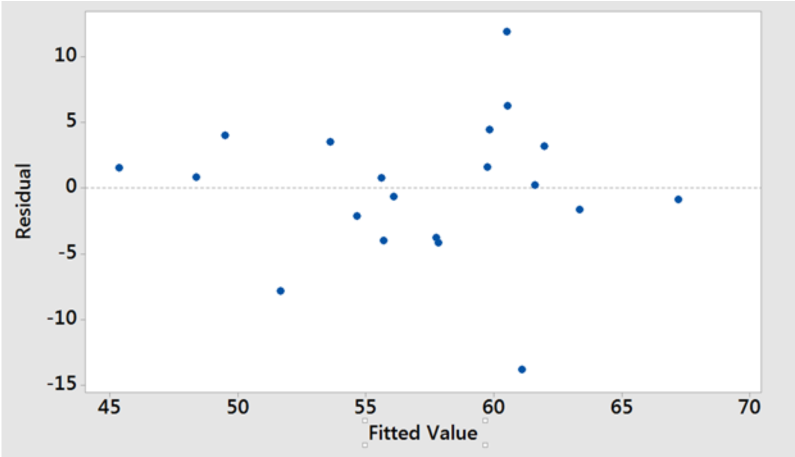

Figure 29: Residual error versus fitted values (Primary break down time) shows variance.

The last thing to check is whether the residuals are normally distributed. The residuals are approximately normally distributed shown by Figure 30.

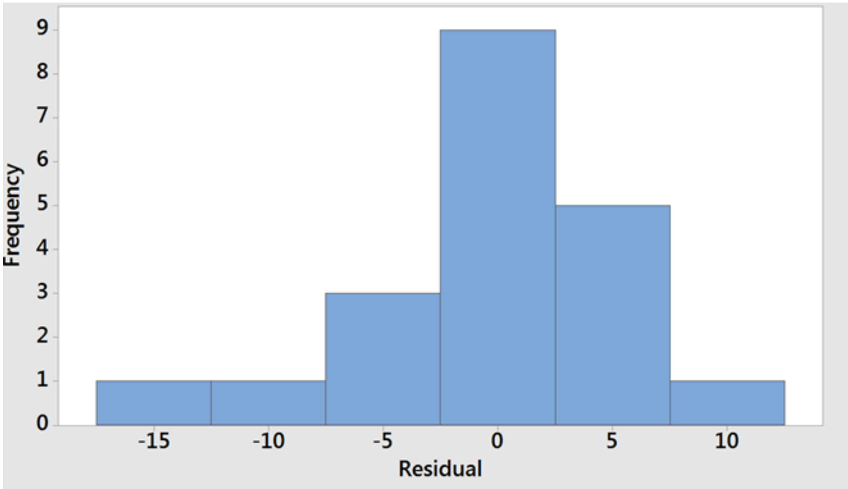

Figure 30: Histogram of residuals showing normall distrabution of residuals.

The regression equation for the edger time was created and it was found that the P value was 0.3, which means the likely hood of there being no relationship was one third. This means the relationship was not significant. So to get edger time in the equation the average edger time was used, which was 26.86 ± 0.57 minutes. The error is the standard mean error for the edger times. The standard deviation was 2.53 minutes.

The total run time for the mill is expressed as:

$$Total\ run\ time\ =\ Primary\ break\ down\ time\ for\ run\ +\ Average\ Edger\ time$$

$$Total\ Run\ time\ =\ (\ 14.83\ +\ 11.11\ Run\ volume\ \pm 5.5)\ +\ (26.9\ \pm\ 0.565)$$

Were units are in minutes and m^3 for run volume..

To calculate the productivity of the operation:

$$Productivity \ = \ \left(\frac{60}{Total\ run\ time}\right) x \ \ (Run\ volume\ \ \pm 0.11)$$

Were run volume is in m^3.

The error for run volume is the standard mean error for run volume data set.

To give an example of the use of the equation the highest recorded run volume (4.71m^3) was feed into the equation. The total run time was calculated to be 94 ± 6 minutes. Productivity was calculated at 3 ± 1 m^3/hr. The total run time recorded was 94.8 minutes, and the productivity was 2.98 m^3/hr. So it is clear to see that equation is a relatively good predictor.

The median quantity of logs in a run was 3. The average log size was 1.2 ±0.03 m^3. If the mill increased their run size to 4 logs this would result in run volume of 4.8 ±0.1 m^3 resulting in a total run time of 95 ± 6 minutes and a productivity of 3.0 ± 1.1 m^3/hr. This would consistently increase productivity over the whole operation.

From the equation it is clear to see that as run volume increase the productivity increases. Presumably there will be a point were productivity starts levelling off, and further study would need to be down with greater run volume variation to get a greater spread of data points.

7. THE ECONOMICS

To see whether there was potential for small scale sawmilling of radiate pine, a discounted cash flow analyses was done, assuming a 5 year business life for the operation. The reason why the discounted cash flow was done over 5 years is that the likelihood of securing a contract for more than 5 years is unlikely. The costs are approximate to what could be expected by the company, the actual cost and cutting rate could not be disclosed due to business confidentiality.

The Capital costs outlined in **Error! Reference source not found.** were the equipment needed to run the mill. The prices of mill, edger, blade sharpening equipment, and green chain were quoted by Paul Marshall the distributer for Wood-Mizer in N.Z. The other prices of equipment were estimated at the market rate for running second hand equipment (Trade Me, 2017).

The deprecation of the equipment over the 5 years was estimated off a Wood-Mizer second hand selling site for edger and mill with an appropriate age (Wood-Mizer, 2017). The green chain and conveyor belt system is a specialised piece of equipment that probably would have limited resale value. The loader, truck and fork lift are depreciated at approximately residual value based on estimation off second hand prices (Trade Me, 2017).

Table 1: The capital cost of the equipment needed for the milling operation.

Capital costs	$NZ	Deprecated value at end of 5 yeas
LT-70 Super Hydraulic Wood-Mizer	80,000	50,000
Loader	15,000	9,000
Edger	25,000	16,000
Chain saws	3,000	0
Blade sharpening and maintaince equipment	6,705	0
Forklift for loading packets onto truck	7,500	5,000
Petrol Water blaster	1,200	0
Green chain and conveyor belt	20,000	8,000
Fire wood and sawdust truck	10,000	3,000
Total capital	168,405	91,000

The interest rate and amount of equity the bank or finance company is willing to lend depends on the ability and likely hood of repayment, cash flow of the business, operation history, skill of the operators, business plan, customer risk, and the economic life span of the equipment needed. In the case of North Otago Sawmilling Ltd the business has been running for 20 years which provides an operating history, cash flows, and very skilled operators. The only obvious thing is customer risk as it only supplies one customer, so the financial strength of that customer will also be accessed by the bank.

In a proven operation the equity lent may be up to 100% on say a new mill with a payback time of 5-6 years (Crawley pers comm 2017). However, for a new operation which is mostly unproven the amount of equity that may be lent would be 50-70% with a payback period of 3-4 years for second hand equipment and longer payback period for new well-made equipment like the Wood-Mizer mill of 5-6 years (Crawley pers comm 2017). This is because the economic life span is longer for the mill than the second hand equipment. The interest rate from the bank could be around 5.5-8.5% and from finance companies between 7- 14% (Crawley pers comm 2017). Finance companies are less risk adverse than banks but charge a high interest rate. To get a loan from a bank is harder than from a finance company.

Knowing the above information on lending and interest rates a 5 year loan repayment was assumed, as 62% of the equipment value is new equipment. Two equity lending rates were chosen 50% equity and 70% equity. Interest rates of 7% being representative of what a banks' interest rate would be and 10.5% what a finance company might charge were used. This was done give an idea of how lending effects the return on investment.

Table 2: Lending on equity and monthly costs required if borrowing.

Interest rate	7%	10.50%
Total equity input 30%	$ 50,522	$ 50,522
Total Borrowed money 70%	$ 117,884	$ 117,884
Monthly repayments over 5 years	-$ 2,334	-$ 2,534
Total equity input 50%	$ 84,203	$ 84,203
Total Borrowed money 50%	$ 84,203	$ 84,203
Monthly repayments over 5 years	-$ 1,667	-$ 1,810

The monthly operating cost are based from ballpark numbers (Marshall pers comm 2017) by the distributer of Wood-Mizer equipment in N.Z. The cost of running the firewood truck was estimated by using the work sampling study to find out the percentage of time that a worker spent delivering fire wood and found that it equated to 1.5 hours per day and assuming 20 minutes unload time. This allowed a round trip of 79 km/day based on Google Maps. Using Google Maps was to allow for the different speed limit restriction when delivering wood. Expense of $1/km was assumed.

The cost of production for the mill to produce sawn timber was $109/m^3. This cost included the cost of producing fire wood, holiday pay for labour, and land rental over the extra month not in production. The cost of producing sawn timber minus the truck running cost and 40% of one works time (shown in the work sampling time study) for fire wood production results in an aproximate cost of sawn timber production of $93/m^3 and fire wood production cost of $16/m^3. This is still an approximate cost as fuel on loader, chain saws and exact labour put into fire wood production is unmeasured. For this reason, the costs were not separated when calculating the discounted cash flows.

Table 3: The Estimated monthly cost for North Otago Sawmilling (Marshal, pers comm2017).

Cost estimation	$NZ
Electricity	600
Fuel (for loader and chainsaws)	1000
Land rental	2000
Labour	18800
Blades	600
Maintenance	500
Running cost for firewood delivery truck	1655
Total monthly cost	25155

The key assumption for estimating the production and the operating cost were that there were 21 working days per month and 11 working months per year. The production was calculated using the conversion ratio supplied by Great Southern, Omarua of 62% conversion of logs to sawn timber. The percentage of the log that was slab wood was 30% leaving 8% for sawdust (Evison pers comm 2017). The sawdust was assumed to be cost neutral as the mill got paid $1 per 25kg sack for edger sawdust and the sawmill sawdust was given to the meat works delivered. So, it would have cost the mill the running of the truck. The labour involved in bagging and extracting the sawdust is a cost which is tied up with the cost of producing sawn timber. Both these cost and revenue were not considered individually; however, labour to extract sawdust, running of the loader and truck are included in the whole operation costs of producing sawn timber.

When calculating the cost for a year, the costs that continued for 12 months instead of 11 working months were debt repayments, land rental, and labour (for holiday pay).

Table 4: The production estimation based on productivity data collected.

Production of North Otago Sawmilling		
Average daily production output volume	11.8	m^3/day
Production per month of sawn timber	248	m^3/month
Production per year of sawn timber	2,725	m^3/year
Slab wood production	120	m^3/month
Slab wood production	1,317	m^3/year

The fire wood price was assumed to be $25/m^3$, the average market rate is $50/m^3$ but this fire wood includes heart and sap wood were as the slab wood coming from the mill is all sap wood which has lower heating value and burns quicker. The price for delivered fire wood was assumed to be not different as there was uncertainty of what volume was delivered and what volume was picked up.

The slab wood accumulated in the yard drying but the assumption was it was sold at the same rate it was produced. The additional income it provided was $32,900 per year. The cost of producing fire wood was intertwined with the cost of producing sawn timber. Because labour and fuel were both used for fire wood production and sawn timber production. All Internal Rate of Returns (IRR) were done including fire wood sale income and expenses.

The contract cutting rate that North Otago sawmilling charge Great Southern, Oamaru is clearly commercially sensitive. A rage between $100 - $150 per metre cube could be expected (Mashall pers comm 2017). A discounted cash flow analyses was done for the range of contract cutting rates.

The sawmilling return on investment with the re-sale of equipment at the depreciated price (**Error! Reference source not found.**) is shown in Figure 31. The contract cutting rate at the required rate of return is $113/m³. The 20% return on investment is the expected rate of return for the industry (Mashall pers comm 2017). If the contract rate changes by $5/m³ the rate of return changes by approximately 10%.

The sawmilling investment without the re-sale of the equipment requires a higher contract rate to achieve the same return on investment of 20%. The difference in the contract rate at required rate of return is $4/m³. However, the relationship is not linear and the breakeven contract rate has a difference of $7.50/m³. It is unlikely that re-sale of any equipment would be difficult but it is a risk and when the contract rate is set this should be considered by the investor.

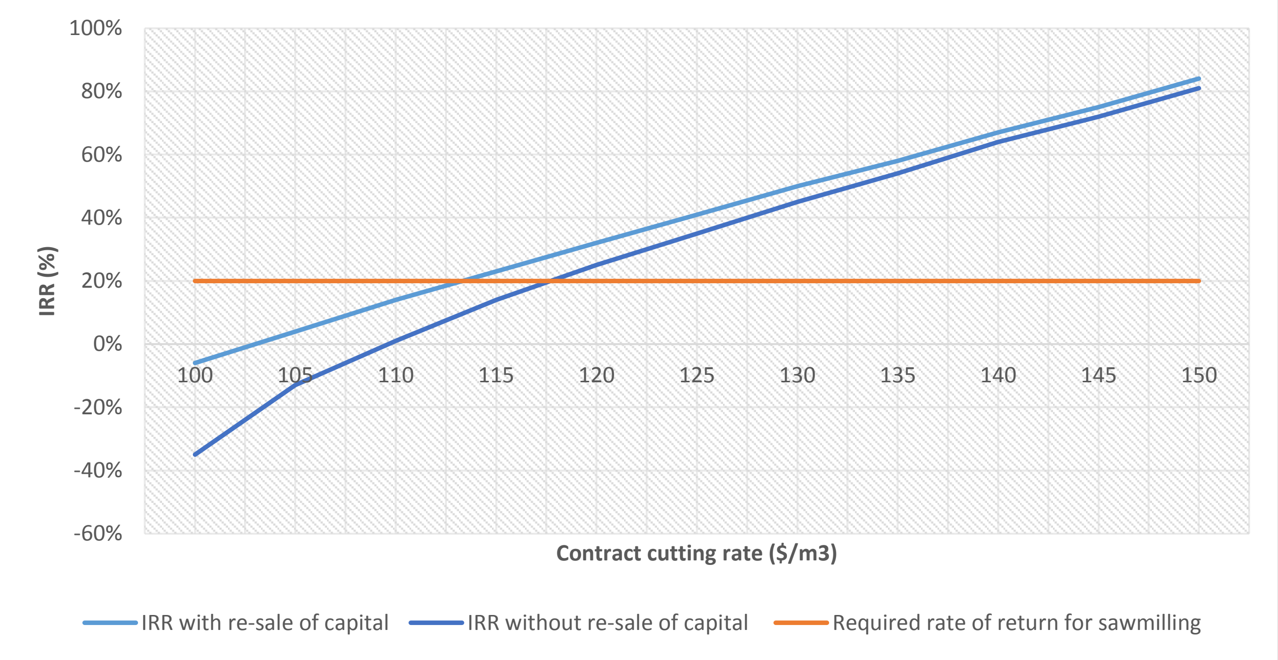

Figure 31: The expected rate of return (IRR) for different investment scenarios.

In Figure 32 the results of a 10.5% interest rate and 30% owner equity input and 50% input, were the two IRR projected lines cross each other is at 10.5%. This is the leverage point at which the two lending options and no lending meet. The advantage of lending at this point is that money can be borrowed to set up business. But the business is exposed to changes in lending rate. Leverage works both ways. So in the case of 70% equity lending the rate of return will be greater than the 50% equity lending because above the 10.5% return on investment the owner is borrowing money at a lower rate than his return on investment. If the IRR is less than 10.5% with 70% equity lending the IRR decreases quicker than with 50% equity landing.

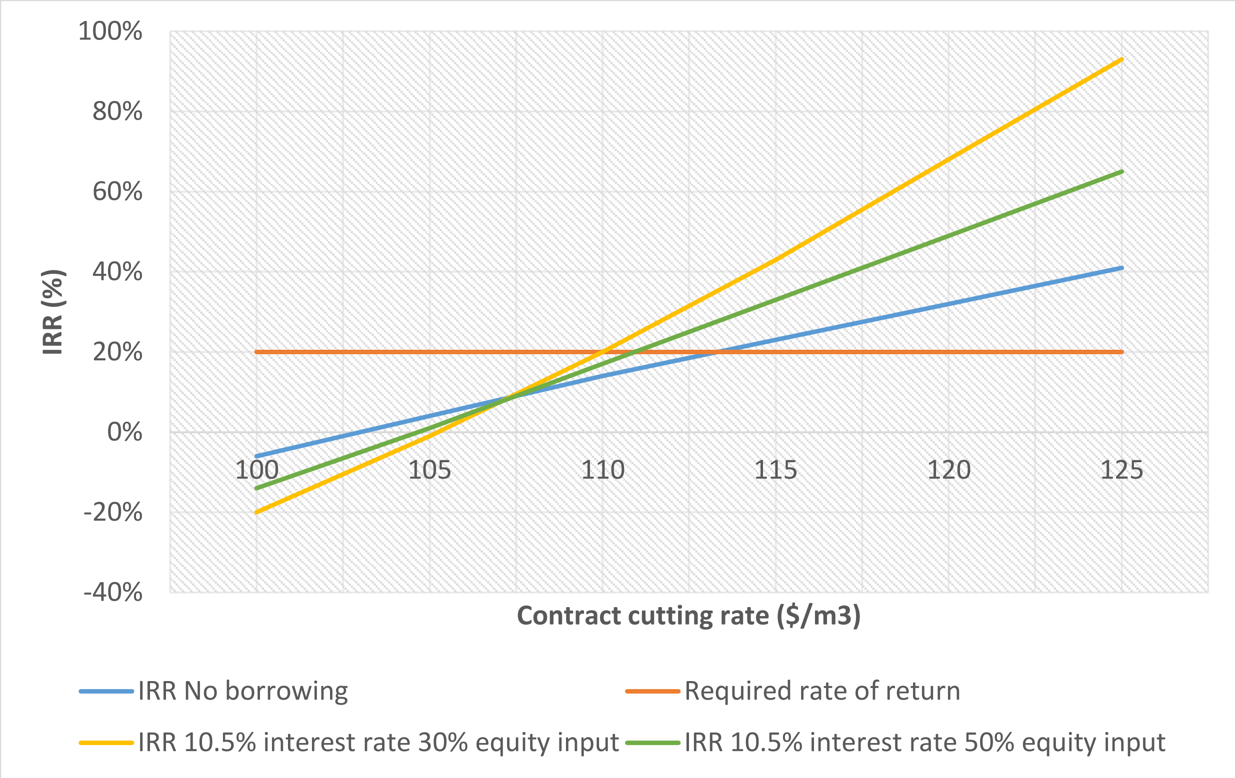

Figure 32: Effects of equity input with 10.5% interest rate (finance company interest rate)

Having a higher lending rate simply shifts the IRR curve to the right requiring a higher contract cutting rate to make the required rate of return (Figure 33)

Lending equity enables a higher rate of return due to leverage. At a contract cutting rate of $125/m^3 the IRR for no borrowing was 41%, the IRR for 50% equity lend was 65% and 70% equity lend IRR was 93% (Figure 32). With the maximum contract cutting rate of $150/m^3 and no borrowing the IRR was 82% (Figure 31). This shows the potential returns with and without lending. However, the leverage works both ways and if the contract cutting rate drops or production drops the losses are much greater.

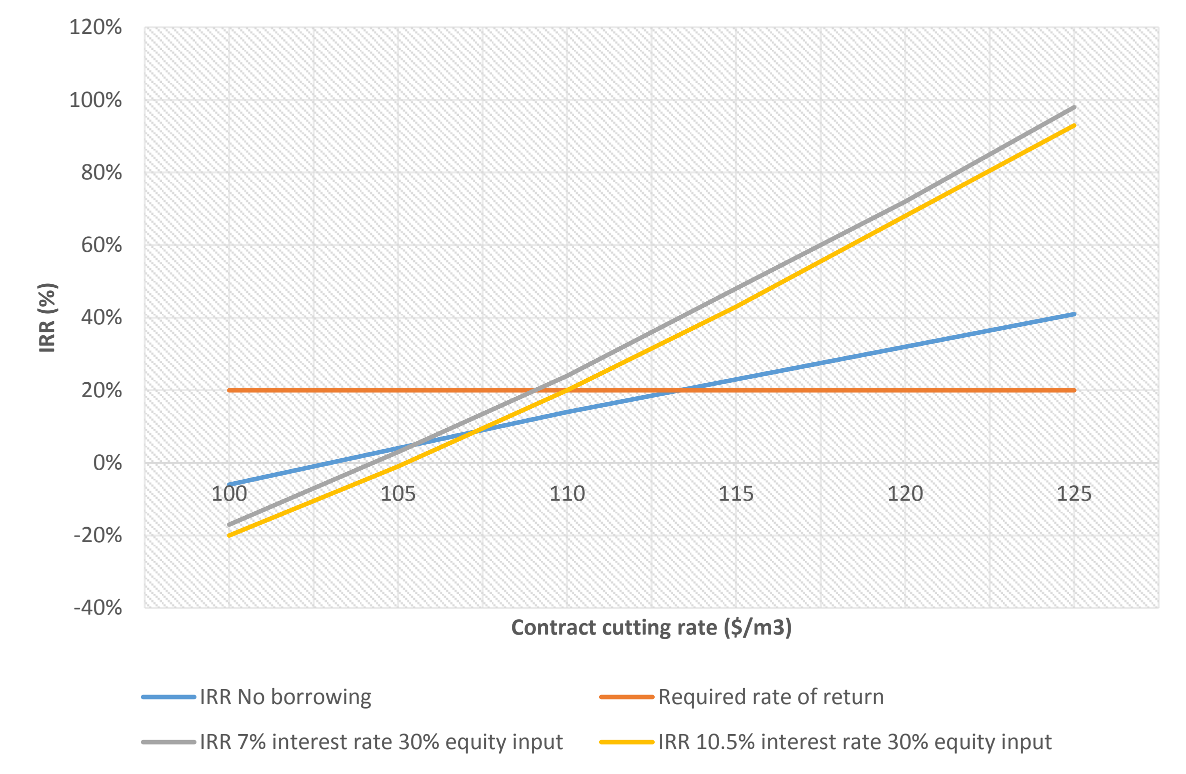

Figure 33: The effect of different interest rates on 30% equity input.

Looking at Table 5 below the lending that enables the lowest cutting rate while making required rate of return is 7% interest rate with a 30% equity input from owner allowing a contract cutting rate of $109/m^3$.

Table 5: The contract cutting rate required to make required rate of return with different lending options.

	Contract rate at 20% IRR ($/m3)
IRR 7% interest rate 30% equity input	109.00
IRR 10.5% interest rate 30% equity input	110.00
IRR 7% interest rate 50% equity input	110.50
IRR 10.5% interest rate 50% equity input	111.00
IRR no borrowing	113.00

In conclusion return from this type of sawmilling has potential to make a very high level of return. However, the returns made are very sensitive to the contract cutting rate as shown in Figure 31. Given that without lending a $5/m^3$ change in the rate leads to a 10% change in return on investment. Given that the contract rate without lending is $113/m^3$ to make 20% is near the lower end of the contract cutting rate range between $100 – 150/m^3$ it looks to be that this type of operation can be quite profitable.

Lending improves the return on investment, but it increases risk as if operation does not produce enough or contract cutting rate falls the likely hood of financial loss is higher than without lending.

In North Otago Sawmilling case they only have one customer so are solely relying on for their business. The customer was using them because they produced high quality sawn timber from the P1 logs supplied to them. But still there is risk in having one customer only. However, this may be due to the fact that they produced relatively low volumes of timber compared large mill so supplying many customers may be not possible do to production.

The profitability of a small scale sawmilling operation milling Radiata Pine comes down to contract cutting rate, productivity and cost of the operation.

8. CONCLUSION

In conclusion, the main findings of this study were: The mill processed 19m^3 per day of log infeed. The productivity ranged between runs from 2.17 m^3/hr to 3.03 m^3/hr log infeed volume. The average productivity was 2.62 m^3/hr. This equates to 1.62 m^3 /hr of sawn timber with a conversion ratio of 62%.

The sampling time study found that the whole operation of 4 workers spent 10.6% of their time on waste disposal, which is the equivalent to one worker spending 42.4% of his time on waste disposal. This highlights the need for an improvement in their waste disposal systems. One quarter of the time for moving finished timber and waiting to put finished timber away combined was spent waiting. Indicating a new system of putting finished timber away has potential to reduce the time by a quarter. The mill spent 3.1% of the operation assisting the miller this mainly consisted of providing weight to prevent the remaining timber from warping this can be replaced by hydraulic clamps that prevent the log from warping.

The productivity equation produced showed that as run volume increased the productivity of the whole operation increased and that the mill should at least increase their run size to 4 logs which would increase their average productivity. However, this trend is not likely to increase forever and there will be some limit that the system reaches when processing larger run volume. Further study with greater run volume variation should show this limit of productivity.

The economic analyses showed that the sawmilling operation could be very profitable. But was highly sensitive to the contract cutting rate. The contract cutting rate was within \$100 - \$150/m^3. The contract cutting rate without borrowing to make the required rate of return of 20% was \$113/m^3. Borrowing money to purchase equipment allowed a higher rate of return to be made than if no borrowing was done because of the effects of leverage. The rate of return with a contract cutting rate of \$125/m^3 gave 41% return on investment without borrowing and with a 70% equity loan at interest rate of

7% the rate of return was 93%. However, leverage works both ways and an investor could potentially make a financial deficit if production dropped or contract rate decreased.

The cost of production for the mill to produce sawn timber was $109/m^3. This cost included the cost of producing fire wood, holiday pay for labour and land rental over the extra month not in production. The cost of sawn timber production was $93/m^3 and fire wood production cost of $16/m^3. The profitability of a small scale sawmilling operation milling Radiata Pine comes down to contract cutting rate, productivity and cost of the operation.

The milling operation has been going for over 20 years milling pruned Radiata Pine on contract. This shows that small sawmills can mill Radiata and be in business for many years. The customer of the mill gets sawn timber from a large industrial mill as well but preferred the timber from the small mill because of the quality of boards that they produce. There would be a demand for a greater sawn timber volume if the mill could produce more. Showing that there is a potential for small sawmills to mill Radiata pine elsewhere in the country.

The weaknesses of this study would be how the batch volume was determined. The mill often left part logs on the head rig. This meant that some of the log volume went into the next run. If most of the log was sawn up into a run then the small amount of time from sawing the log up in the previous run was added to the run in which the majority of the log was sawn up into. This method was assumed because most of the time there was a part log left on the head rig. So on average, the volumes in the batch would be the same as the volume of logs included in that batch. This assumption may have led to more variation in the primary break down time data than if exact volumes were measured exactly in the run. A larger data set may increase the significance of the data. Where no significance and no trend was found there would be no point in collecting father information on those measurements.

Suggestions for further research would be to change the run size significantly to see if bigger run size will increase productivity, allowing a greater range to the productivity equation. To study the effect of introducing a system of moving the finished timber to the packets of timber in a several big loads rather than large amounts of small trips. To study the primary break down of the log to see how cutting strategy effects the time it take to process.

9. RECOMMENDATION

Some areas that could immediately improve production are:

- Potentially if scheduled breaks occurred at a set time and the current batch didn't need to be finished before a break. This would enable larger batch volumes to be processed, so productivity would increase and workers would not become fatigued because of longer run times.

- Putting finished timber away by one person, or letting the finished timber accumulate to be either taken out by hand or on a trolley would reduce the waiting time at the edger. Waiting time equates to one worker waiting for 6.8 hours per week based on a 47 hour week. If a trolley was used this would reduce the travel time between the edger and the packets of timber as well.
- Having an extractor system for the edger sawdust would free up 17.6% one worker's time this equates to 8.3 extra hours per week for a worker.
- If fire wood delivery was stopped this would free up 7 hours per week for one worker.

These managerial changes are relatively simple things to do, they would immediately free up 22 hours per week for one worker or equivalently 5.5 hours (330 minutes) of the whole operation per week based on the sample time study. This time then can be reallocated into producing more sawn timber. The average run time is 87 minutes, if the 330 extra minutes of the whole operation were used it would allow 3.8 more runs to be completed each week. With an average run volume of 3.8 m^3 and being able to process 3.8 more runs per week this enables 14.4 m^3 of log infeed to be processed per week, which is approximately 9 m^3 of finished sawn timber per week extra.

10. ACKNOWLEDGEMENTS

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