UNIVERSITY OF CANTERBURY

SHOVEL LOGGING WITHIN NEW ZEALAND: TIME AND MOTION STUDY

3rd Professional Engineering Project Report

By

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Executive Summary

This paper presents a production study of modified excavators capable of grappling and shifting tree stems by rotating and pushing with hydraulic driven arms. The study looked at a Caterpillar 325B within a ground-based setting of medium terrain and a Volvo FC3329c set in a typical cable yarder setting of medium to steep terrain. Both blocks observed being yarded used these machines to handle Pinus Radiata typical to New Zealand forestry with highly varied piece sizes. The stems were recorded between 0.4 - 3.1 m^3 and 1.3 - 3.9 m^3 for *Day 1* and *Day 2* respectively. For this study it can be assumed that 1 m^3 of wood was equivalent to 1 ton of wood, as extraction was of 'green' wood.

The purpose of the study was to develop and present information concerning the application of a logging technique that has been utilized in the industry for a number of years, but little has been documented regarding the applicability within New Zealand forestry environment. The purpose was accomplished by, 1) estimating the production rate, 2) estimating the logging costs over extraction distances, and 3) evaluating the current machines applicability and effectiveness for shovel logging in New Zealand.

Time and motion studies were used to identify the utilization and production per swing of the shovel machine. This was then extrapolated out on the assumption that yarding time is linearly related to distance yarded. Henceforth, productivity was found using stem size estimations for each cycle, and a relationship between productivity and extraction distance was made possible. Significant variables in production included: machine/driver combination, terrain or wood flow direction, and yarding distance. The relationship between production of load per cycle and yarding distance was assumed linear until the machines capability has been reached.

On relatively flat ground the Cat 325B on *Day 1* was observed to have travelled in a serpentine pattern, systematically swinging the stems closer to the roadway or landing on each pass. However on steeper slopes seen on Day 2 it became apparent that the terrain may prevent such an efficient system; here a different downward zigzag type of pattern was utilized which allowed the stems to be moved in a favorable manner to the slope and achieved small grouped piles ready for the subsequent extraction method.

The actual yarding production rate on the setting in *Day 1* was found to be 55 tons/PMH when yarded 100 metres. Depending on the contractor's requirements, production drops to an unacceptable level (18 ton/PMH) for extraction distances over 300 metres. *Day 2* showed a production of 65 tons/PMH on steeper terrain, which was determined to be influenced by the machine type. The unit rate for extracting wood in this manner was found to be very efficient for short distances (<50m) at \$1.82 and \$1.52 per ton on *Day 1* and *Day 2* respectively. This unit cost per ton is found to increase with distance to a point where the extraction process consumes as much as 45 percent of the contractors' allocated logging rate at 300 metres, which is unacceptable and a premium in logging rate should be sought by the contractor if this method is to be carried out. The specialized shovel machines were observed and compared in terms of applicability and it was found that the larger Volvo could handle more volume of wood per cycle and consequently had a higher productivity and lower unit rate for yarding, it was there better suited for New Zealand forest conditions than the smaller alternative Cat 325B.

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1. Introduction

Shovel logging (or Hoe Chucking), uses an excavator to swing logs in a non-tractive manner to a landing or road-side for processing or further extraction. This method of shifting stems poses as an alternative to other conventional ground-based and cable extraction methods using skidder/forwarders and skylines respectively.

1.1 Background

The Shovel logging technique was developed in Washington in the early 1980's, with a natural outgrowth of hydraulic excavators used for road construction modified to suit logging with dead thumbs assisting the movement of right of way timber (Sloan, 1992). Eventually the in-efficient dead thumb was replaced with a live heel which allowed better movement and control of the stem. Today most excavator manufacturers produce specialty forestry excavators designed for the principal means of yarding logs with options for boom designs, undercarriage layout, cabin height, protection and grapple designs that best suit the contractor's application.

The shovel starts at the back and systematically moves through the setting moving the stems closer to the landing site. The shovel usually travels unloaded. Log movement occurs when the stationary shovel picks up the stem and by rotating, swings the stems closer to where another machine can access them. This method requires multiple handling of each stem and therefore the effectiveness can be controversial among contractors and forest managers, however shovel logging is regarded as very productive and cost-effective in places of the Pacific North-West (Fisher (A), 1986).

Excavators being used in the field study are thought to be of typical size for shovel logging in New Zealand with a range of weights between 25 – 40 tons. The Shovel observed within the operation of *Day 1* can be seen in *Figure 1* as a smaller 28 ton machine, which negotiates the medium terrain with ease. A stockpile made earlier can be seen uphill of the machine ready for further extraction with a grapple skidder.

Figure 1. Cat 325B Shovel seen on *Day 1*

1.2 Need

Research papers carried out in the Pacific North West suggest contractors have an average shovel yarding distance of 183 metres within easy to medium terrain (Fisher (A), 1986), thus suggesting shoveling may occur to a distance of over 300 metres in some cases. Contractors in New Zealand are known to actively utilize shovel logging as partial and full extraction methods however it is only preferred in areas of difficult terrain or small volumes of wood. The main reasons for these preferences are due to the machines ability and flexibility to perform in terrain that would otherwise require extensive earthworks or harvest planning in order to extract wood. There has only been one technical release carried out to describe this process within the New Zealand forest environment (Hemphill, 1986), however many contractors' are aware of the capabilities and opportunities arising from shovel logging from a trial and error basis.

1.3 Objectives

The objectives for this study are to:

For a shovel logged unit;

1. Estimate the production rate,
2. Estimate the logging costs over extraction distances,
3. Evaluate the current machines applicability and effectiveness for shovel logging in New Zealand.

1.4 Scope

This study reports on machine effectiveness for the primary tasks of ground-based yarding with an excavator (shovel). It is designed to measure the production rate, unit cost and ultimate unit load that results from both a Cat 325B and Volvo FC3329c hydraulic excavators used to yard logs. The case study was limited to two sites, two similar machines and one type of yarding method.

1.5 Literature Review

Considerable research has been carried out on the shovel systems in the Pacific North West regarding productivity and environmental considerations. These publications found shovel logging to be highly productive systems requiring minimal labour units (Fisher (B), 1986). They describe the process to have significantly less earthworks with almost no tracking or landing needed as the stems may be processed at the roadside.

Elemental time studies on shovel logging machines in the past have determined the main factors influencing hourly production to be: Butt diameter, slope and volume. The case study carried out by Fisher found a shovel to achieve a productivity of 54.5 m^3/scheduled machine hours in a Douglas Fir stand of medium to steep terrain (0-60%) (Fisher (A), 1986). The stand had an average piece size of 0.75m^3 which is comparatively small compared to traditional New Zealand piece size at maturity; however this study identifies similar shovel yarding techniques for such varying terrain. It was stated that the most effective way to log stems on flat ground was to employ a serpentine pattern of machine paths, where the shovel moves around the boundary of the block and methodically swing the stems closer to a landing/trail.

Skidding is regarded to have high production rates when coupled with favorable conditions; a regression model was established from major contributors affecting the yarding method's productivity (Wang Jinxin, 2004).

- Butt Diameter
- Merchantable length
- Stems per load
- Payload per turn
- Turn distance
- Terrain (slope)

Most of these parameters relate to the load and unload times of a skidder, and this limits the productivity of a skidder over short distances. The actual loaded moving time of a skidder can be highly productive. This method may become more/less favorable than shovel logging at some distance.

Also seen in Washington was a push for environmental regulations to be relaxed so contractors' could shovel areas that were typically only high-lead cable settings (Sloan, 1992). This practice allowed stems to be yarded in a downhill manner rather than the traditional uphill cable yarding methods. Cost estimations found this trial system to have rates of $6.33/mbf-eq and production of 11.6 mbf-eq./hour which is very low comparatively and timber volume output is quite high.

A study done on compaction of soil beneath excavator in Oregon found the shovel machine to increase the bulk density of the soil by 7.7% compared to undisturbed soil nearby (Flock, 1988). Environmental considerations of the machines suitability are therefore significant. It is therefore the land-owners responsibility to decide whether it is better to employ a more expensive yarding system that causes less compaction or to use a less expensive yarding system that causes more compaction, this decision should not be made purely on economics.

2. Field Study Design

2.1 Study Area Description

Field studies took place during the month of August 2013, which showed warm winter conditions for New Zealand. It had been raining at both sites prior to observations taking place, but it appeared that the machines were not affected as a consequence. Rocky outcrops situated on the ridgeline seen on Day 2 did not affect the productivity of the machine and therefore regarded as insignificant to shovel logging. Harvest managers of two Otago forest owners made contact with times at which crews were carrying out shovel logging. In order to gain a successful study, both sites were visited to get an understanding of the shovel's effectiveness in each case. While onsite the weather provided cloudy and cold temperatures, however there was an insignificant amount rain and wind to affect operations.

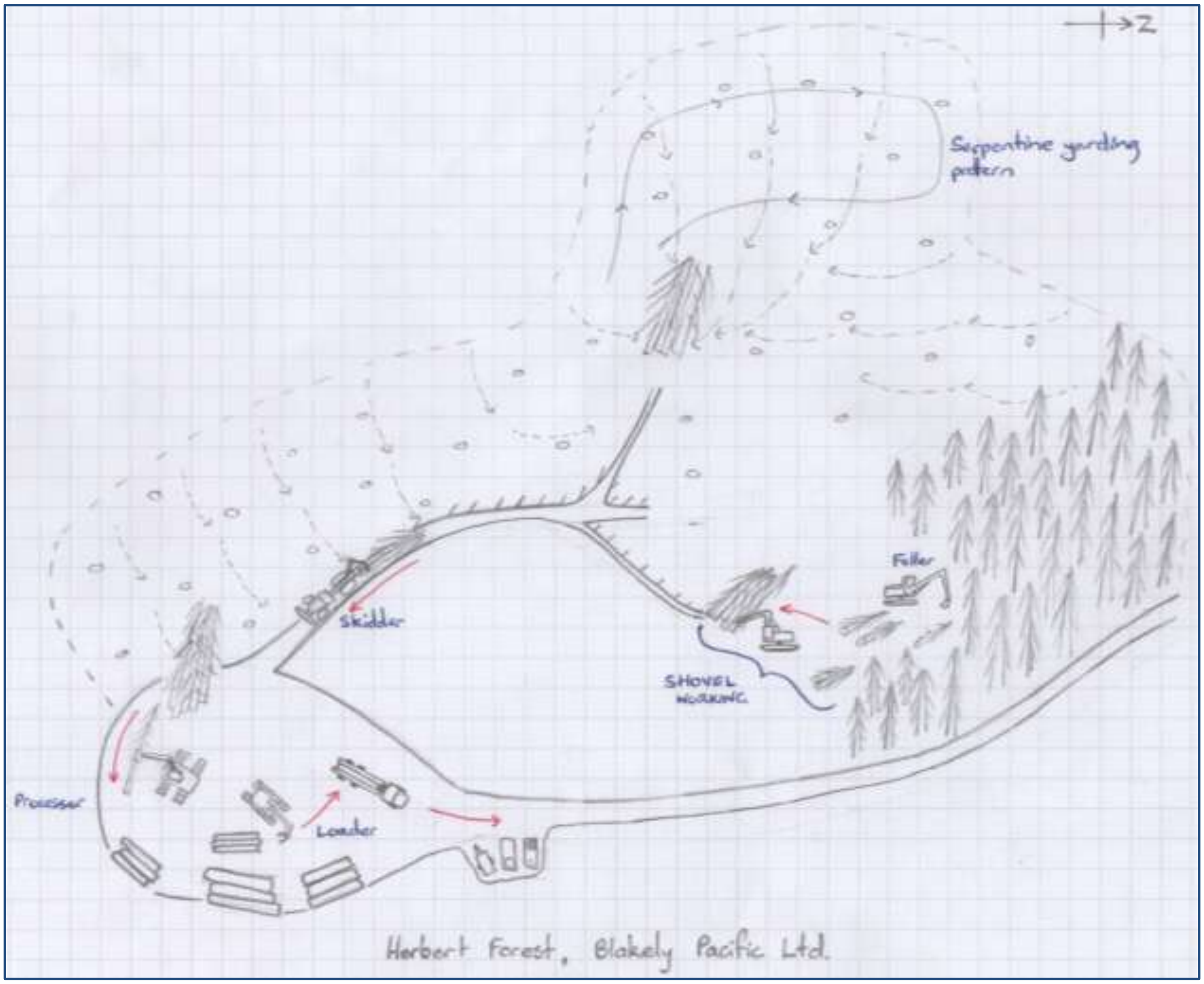

Figure 2. Schematic of Ground-Based Setting, Day 1

The first field-day (Figure 2), based in Herbert Forest with unpruned Radiata Pine being two-stage hauled to landing using a shovel and grapple skidder. The area being harvested was destined for skid trail construction, gradient varied onsite between 15 and 25 percent with steeper terrain not covered by the shovel while observing. Wood being shoveled tended downhill across the slope which had previously been bunched, therefore no breaking out was required with the shovel.

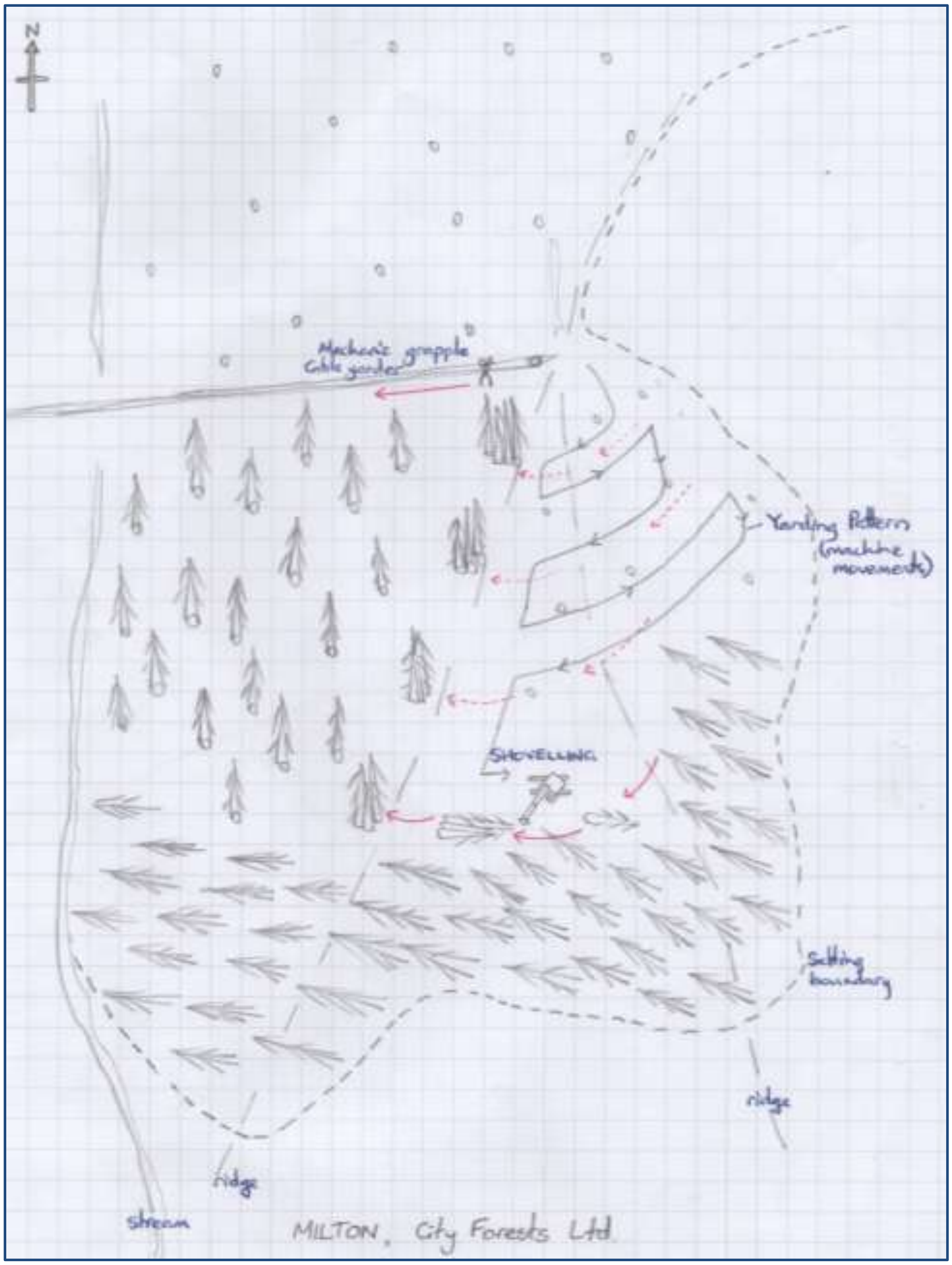

Figure 3. Schematic of Cable-yarding type setting, Day 2

The second field day (Figure 3), was based in Milton with large pruned Radiata Pine. The shovel was found to shift stems from a small block of trees over the ridge to the tail hold where they were cable yarded from. Gradient in the setting varied from 10 to 50 percent, of which was all covered by the shovel. Wood flowed across slope to the ridge and was bunched on the face in a way favorable to the grapple swing yarder. From carrying out this shovel process, the shovel was observed to follow a zigzag pattern that allowed wood to be moved to the ridgeline with ease (shoveling uphill is unfavorable).

2.2 Logging Operation Description

The shovel operations included an operator and shovel; the excavator setup for shovel logging had certain configuration variances between sites shown in Figure 4 below. Both of the operators were highly skilled at handling the shovel machine. The differences in machine configuration and work tasks were seen to be:

- *Day 1* included a Cat 325B with 3.4m wide tracks and a conventional grapple attachment similar to that used for loading trucks. This machine did the job of shoveling and site preparation for skid trail construction.
- *Day 2* involved a Volvo FC3329c with Satco felling head and 3.6m wide track base. This machine primarily shoveled however was used to shift the tail-hold for the hauler also.

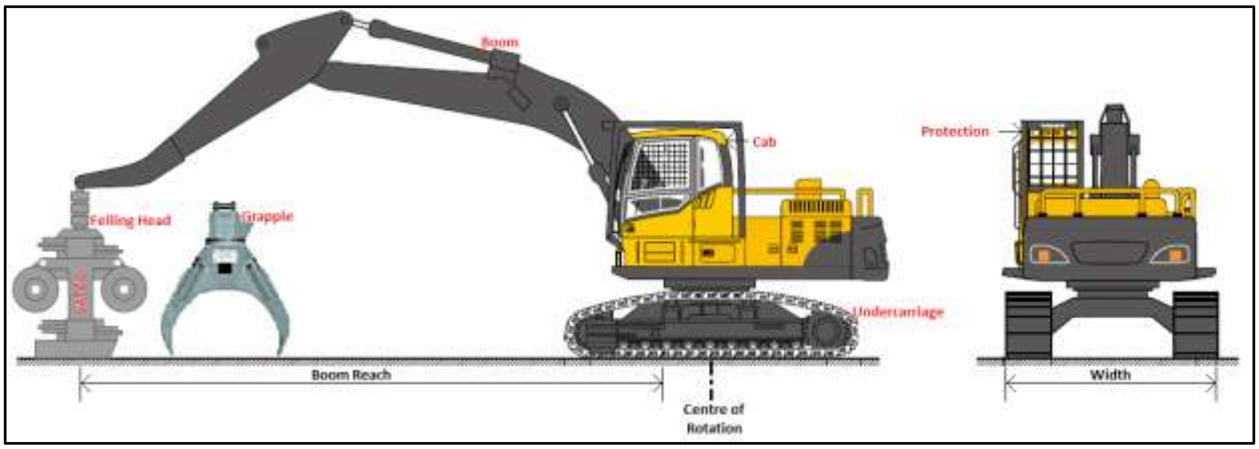

Figure 4. Shovel configurations observed: Day 1 utilized *Grapple* and Day 2 utilized *Felling Head*.
Note: adjustments have been made from original figure (Volvo Construction Equipment, 2004)

2.3 Measurements Taken

2.3.1 Shovel Paths

To find the distance which a shovel can shift a stem with a full swing, three quarter swing and half swing was measured using a measuring tape at marked points on ground. A sample movement of the shovel was measured with the measuring tape to calibrate the spotter and then approximations made when carrying out the study.

Time taken to carry out each task was measured using a stopwatch accurate to the nearest second, it was determined that this level of accuracy was adequate for the application.

2.3.2 Stem Size

In order to estimate the volume being shifted by the shovel, a sample of stems were measured at each site to categorize/group the stems. This method allowed the shovel operator to work uninterrupted and the observer could be positioned at a safe distance. The average volume for each small, medium and big stems seen in Table 1 and Table 2 can therefore be assigned to notes taken by the observer for each cycle. Sample stems were chosen onsite to give a good representation of what piece size range was present in each stand respectively. The data found was site specific to gather productivity specific to that shovel of interest, and therefore the data groups are not comparative between sites. The distribution of piece size is shown in Figure 5 and Figure 6 in *Part 3.1*. As the time study was taking place, notes were made on which size stems were being moved in each cycle.

2.3.3 Time and Motion

In order to derive the productivity and unit cost for shovel logging, total time spent shoveling and total volume shifted were needed. A time and motion study was designed to do this, taking advantage of the observer being onsite for the entire study period noting time taken for each corresponding stem size. The shovel's use of time was divided into six parts – moving, loaded swing, unloaded swing, shifting stumps/slash, operational delays and mechanical delays. Each part was defined as follows:

- Moving: This activity includes all periods of time that the shovel is moving on its tracks, mainly unloaded; however cases seen on *Day 1* where the shovel moved with logs and it was noted as a separate category for further discussion. This started when tracks first start moving and finished when the grapple touches the log for the loaded swing. Examples of moving includes: moving between bunches, moving to the ridge for maintenance and scheduled breaks.
- Loaded Swing: This activity includes all time when the grapple is moving the stems in a systematic shoveling order. Starting when the grapple touches the stem (end of moving/unloaded swing) and finishes when the stem is let go. Examples include moving stems between bunches, shunting a stem to adjust its orientation to further gain distance.
- Unloaded Swing: This activity includes all time that the shovel is rotating between bunches without logs in the grapple (return trip from loaded swing). Starting when the stem is let go and finishing when the next stem is touched.
- Shifting stumps/slash: This activity is the time needed to clear a path or arrange the pile for ease of use, also including unloaded swing time. Starting when the stems are dropped and finishes when a new stem is picked up or the shovel starts moving. Examples of this include: stacking the bunches, throwing slash/stumps down the hill.
- Operational Delay: This activity includes all time that the machine is not working toward its primary task of shoveling, but is benefiting logging operation. Starting when the shovel stops doing its task (drops stem, or starts moving away) and finishing when the machine starts back (moves into shovel area or starts engine up again/swing toward bunch). Examples of this includes: moving the tail-hold for the swing-yarder or talking on the hand-held radio to other workers.
- Mechanical and Personal Delays: This activity is the time that the shovel cannot work on its primary task or any other tasks that benefit the operation. Starting when the shovel stops doing a task and finishing when the machine is back at a task. Examples of this include: replacing a

worn O-ring in the grapple attachment, repairing a broken stabilizing bar (wishbone) in the felling head or talking on phone to persons outside of the logging crew.

2.3.4 Production

Adding together the times spent for each shoveling activity and disregarding time that the shovel was used for alternative jobs, the productive yarding time could be calculated. During each loaded cycle the estimated log size is coupled with the average log volume for each size, totaling the volume will give the shovels production (assuming that 1 m^3 wood is equal to 1 tonne mass). The production with distance will therefore be assumed to be,

$$P_x = \frac{dist.(1)}{dist.(x)}(P_1)$$

When: P_x = Theoretical productivity at yarding distance, (Ton/PMH)
P_1 = Productivity at calculated yarding distance, (Ton/PMH)
dist. (1) = Standardized yarding distance (one full swing or 18m in these cases (m))
dist. (X) = Theoretical yarding distance (metres)

Note: Production has been calculated on an average yarding distance of 100 metres, it has been estimated for several other yarding distances to establish a productivity curve. This relationship neglects any increase or decreased caused by longer or shorter yarding distances. Likely effects include: Ease of log-handling due to orientation and stacking or conversely clogging of space around the shovel.

Unit cost rate for the machine and the labor unit required to operate the machine were calculated using the LIRO Costing Model with typical current forestry values (LIRO, Appendix 2). The unit extraction cost per ton can be established with productivity and unit cost.

3. Results of Field Study

3.1 Size Distribution from Sample

A sample of tree volumes was taken onsite; the distribution can be seen in Figure 5 and Figure 6 below. Butt diameter measurements were used to distinguish the different categories of volume for each site (*Appendix 1*), as this could visually be seen in the field, however length and bulk was also noted by the observer and this can be seen as overlaps in the grouping. The number of points found in each size category reflected the amount of data points observed. The medium sized log was the most common observed size for *Day 1*, supplementary to this it was found that the stem sample had similar proportion of medium stems. This allows for strong correspondence between what was estimated from visual estimations to what was recorded from the sample size.

Day 1:

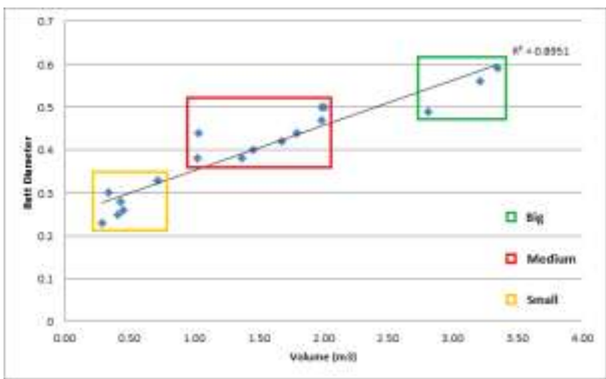

Figure 5. Volume distribution with Basal Area (*Day 1*)

Table 1. *Day 1* Log size estimation

Day 1	Size (ton)
Big	3.1
Medium	1.6
Small	0.4

Day 2:

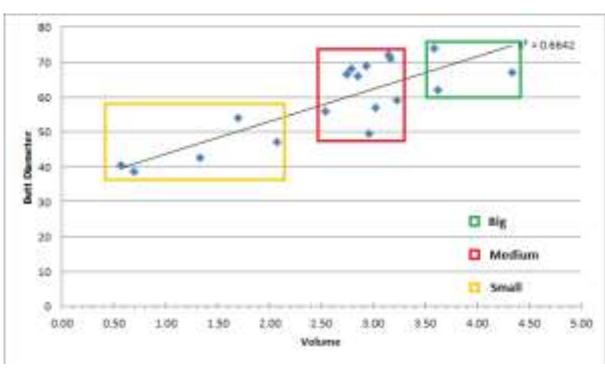

Figure 6. Volume distribution with Basal Area (Day 2)

Table 2. *Day 2* Log size estimation

Day 2	Size (ton)
Big	3.9
Medium	2.9
Small	1.3

The mean volume for each size group (small, medium, large) found in Figure 5 and Figure 6 above were used to determine the average log size approximation listed in Table 1 and Table 2. These values are only estimates limited to a given sample size of 20 stems found in stockpiles on-site. A comparison of sizes cannot be made between *Day 1 & 2* as they were only determined for the process of computing productivity for each machine separately.

Day 1 data can be seen in Table 1 to have an average medium piece size of 1.6 m^3 (ton), which is small for typical Pinus Radiata settings in New Zealand. It is therefore intuitive that the machine can shift multiple stems per grapple, which may be seen in Figure 7 within *Part 3.2*)

3.2 Shovel Machine Suitability

The following sets of figures are shown to display the machines suitability for shoveling in New Zealand conditions and optimizing each machine's productivity. Figure 7 displays how the Cat 325B's (*Day 1*) productivity changed with pieces per cycle, a clear observation may be made between the average points (shown as red points), hence determining the optimum piece count for this machine to be three stems per cycle. Shown in green is the productivity when the machine grabs and pulls the stems along, which is much lower than stationary shoveling. Data from *Day 2* was not comprehensible in this fashion as the site had a larger piece size and therefore the machine could only swing one piece at a time in most cases.

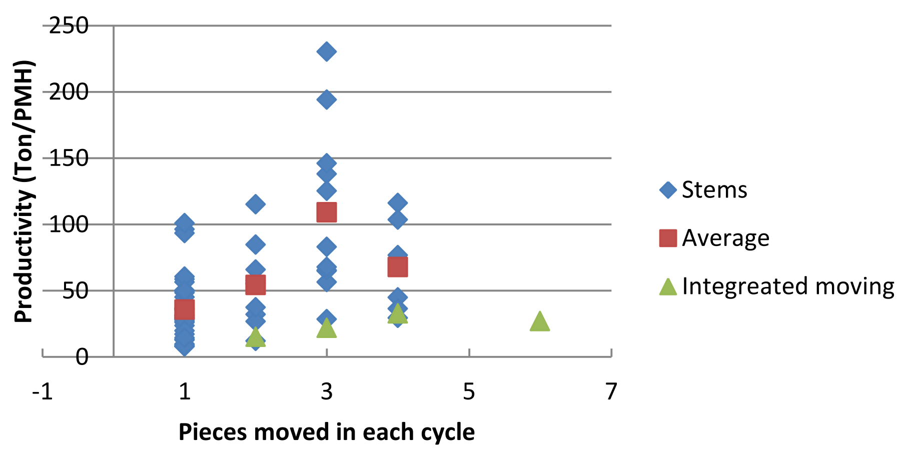

Figure 7. Optimum machine efficiency relationship with piece count

In the following Figure 8 and Figure 9, a trend of increased production relative to tonnes per cycle is evident. The productivity shown is given at 100 metres extraction distance. The machines seen for each day have optimums depending on their power and weight outputs. The Cat 325B can be seen to have its highest productivity when the load is around 4.5 tons per cycle, which agrees with the piece count seen in Figure 7. The Volvo's productivity was seen in Figure 9 to be increasing as load increased, with a high productivity above 5 tons per cycle. This analysis was approximated to show a linear relationship between load and productivity that will reach a maximum and subsequently drop, in reality a higher order polynomial would better suit the relationship but would require significantly further data computation.

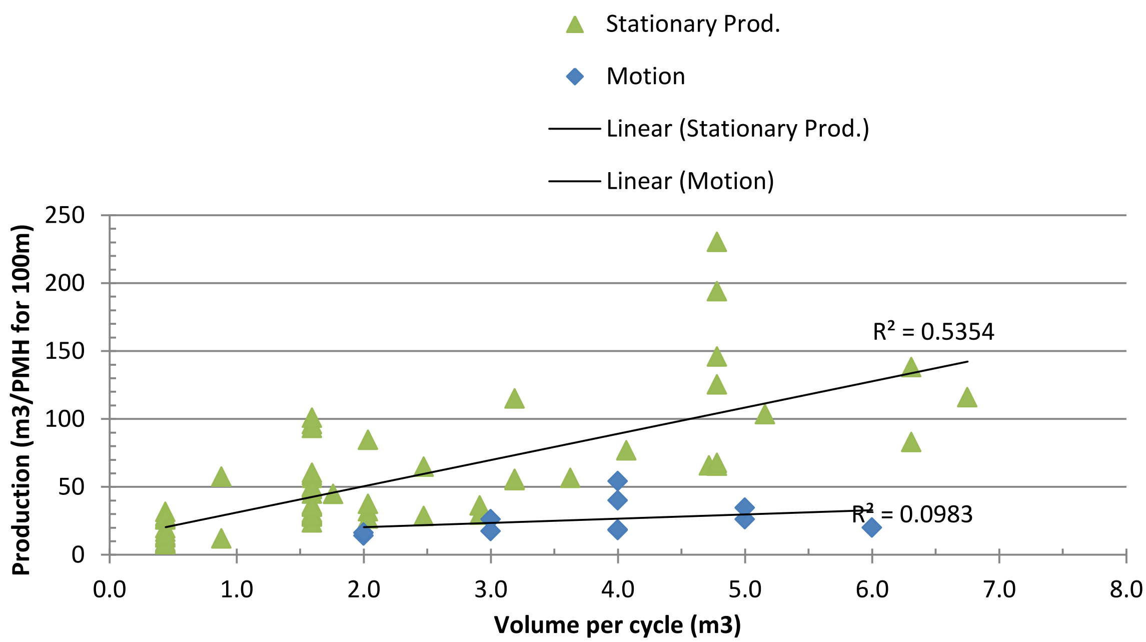

Figure 8. Productivity of Cat 325B on Day 1

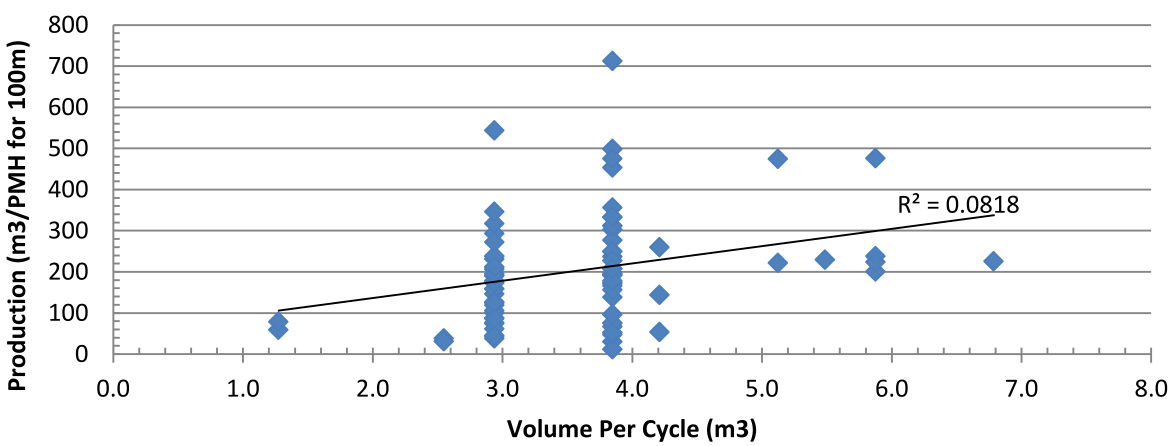

Figure 9. Volvo FC3329c Productivity on *Day 2*

3.3 Shovel Utilization

Due to limited data for *Day 1* shovel machine, utilization could only be identified for *Day 2* data. This is shown in Figure 10 where loaded, unloaded, moving and shifting stumps/slash are included in a Shovels' primary tasks. While observations were carried out a non-scheduled mechanical delay occurred (detailed explanation in *Part 2.3.3*), this was incorporated in the time-study however a new machine like the one seen is expected to have less down-time. The machine therefore had a utilization of 63%.

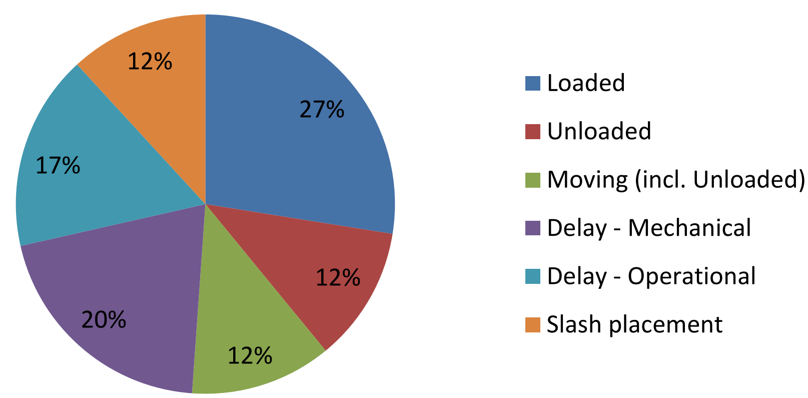

Figure 10. Volvo FC3329c Shovel utilization

3.4 Shovel Efficiency

From the data collected, the total time spent Shoveling with the total volume yarded was used to determine the productivity. Results in Figure 11 are given in productive machine hours, to assess the productivity when the shovel is solely carrying out its primary task. Data from *Day 1* was lacking sufficient moving and slash placement data but satisfactory unloaded swing data points allowed an approximation of productivity for this system. The two machines had different productivities due to terrain, wood type, machine and operator carrying out the shovel task. Conclusions may be made from this graph based on the assumption that yarding time has a linear relationship with distance yarded. Shovel logging can be seen to have a high production rate over short distances, which quickly declines as more swings are required. The production was coupled with unit rate cost for the machine and operator per productive machine hour seen in Table 4, to give an estimate to the cost of wood extracted with distance.

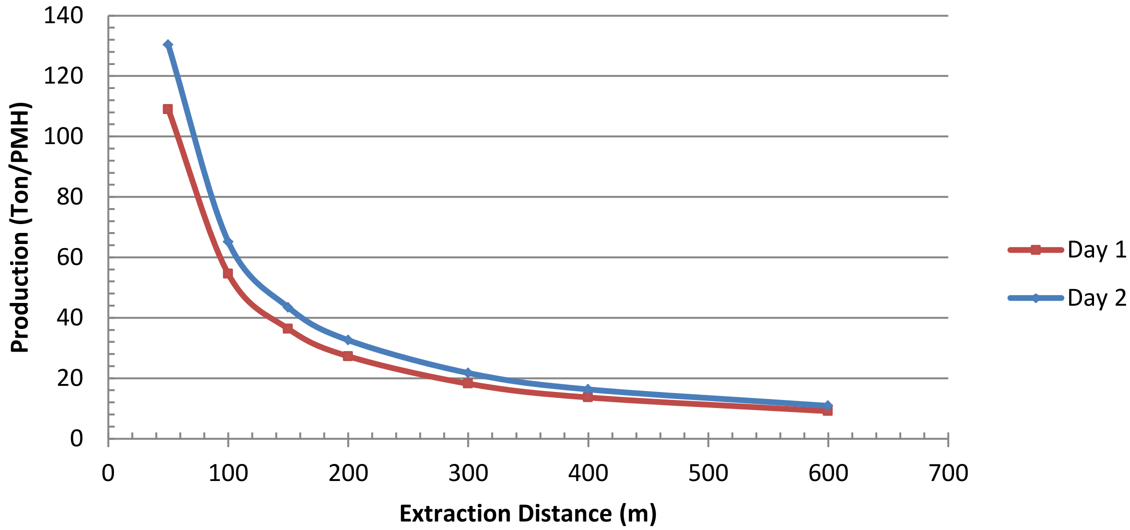

Figure 11. Shovel effectiveness: Relationship of productivity with yarding distance

Table 3. Estimated Production and Extraction Cost with different yarding distances

	Day 1		Day 2	
Extraction Distance (m)	Production (ton/PMH)	Extraction Cost ($/ton)	Production (Ton/PMH)	Extraction Cost ($/ton)
50	109	1.82	130	1.52
100	55	3.64	65	3.04
150	36	5.45	43	4.56
200	27	7.27	33	6.08
300	18	10.91	22	9.12
400	14	14.54	16	12.16
600	9	21.81	11	18.24

Table 3 shows the low labour requirement and simple shovel method can achieve low rates. If the terrain and road line maps allowed for less than 100m extraction distance, this method would be highly efficient with greater than 55 tons per productive machine hour and a low unit cost ($/ton) relative to the total logging rate ($/ton) (Table 4). It can be seen in Table 3 that production becomes very low at distances further than 300 metres and equally costing the logger a significant amount ($).

If a system required shovel log extraction for a long extraction distance (such as 300m) and needed to upkeep a certain production level to satisfy concurrent machines (processor), an additional shovel machine could be introduced in sequence to decrease the extraction distance of each machine. The individual stem extraction distance per machine would therefore be 150 metres and double the production could be achieved. The overall cost of having another machine working would be the same per ton as one machine extracting all of the wood.

Day 2 data in Table 3 shows that shoveling in steep areas otherwise thought of as cable yarding zones (20-60%) is achievable and inexpensive in favorable conditions at low distances. It can be seen that shoveling within 50 metres of the landing or trail will cost the logger an insignificant amount ($) of the logging rate ($/ton). Furthermore it would be highly beneficial to have a shovel orienting stems on the cut-over in correspondence with a cable yarder to give favorable loading times and quicker yarding cycles.

Table 4. Summary of New Zealand Ground-Based Logging and Cable Yarding Data (Visser, 2013)

	NZ Average for 2012	
	Ground-Based	**Cable Yarding**
Extraction Distance (m)	193	189
Productivity (t/SMH)	28.1	23.5
Logging Rate ($/t)	25.30	35.13

4. Conclusion

4.1 Discussion

4.1.1 Production rate

The average production rate of a Shovel in New Zealand's medium to steep terrain (10 – 50%) was found to be around 55 and 65 tons per productive machine hour on *Day 1* and *Day 2* respectively (Shoveling 100m). This represents up to five consecutive swings with each stem. Production was dependent on the load per swing (volume of wood in each grapple) with optimums seen in Figure 7 for *Day 1*. The production of the average extraction distance to be Shovel Logged must be closely correlated to the production of the rest of the harvest system. It can be seen in Figure 11 that shovel logging may be the limiting factor which holds everything back if large extraction distances occur, some as low as 18 ton/PMH at 300 metres extraction. From Figure 7 it was clear that moving with stems (dragging stems by tracking the machine) was slow and unproductive with this type of machine, however if the machine has to relocate in that direction it would be suitable to take some wood with it to its next stationary point of shovel.

It is likely that a larger machine will allow higher loads per swing and therefore ultimately higher productivity, which was displayed in *Day 2* with higher productivity in steeper less favorable terrain (Figure 11). Additional machine unit costs and environmental disturbance caused by a larger machine would need to be monitored.

4.1.2 Cost of Shovel Logging

The unit cost was incorporated into the production rate to give a unit extraction rate for the wood over distance retrieved. It was found that the Shovel working on *Day 1* in a ground-based setting could extract wood up to 150 metres at a cost to the contractor of under $5.50/ton, intern making up 22% of the logging rate paid to the contractor by forest owner (Table 4). Extracting wood further than 300 metres would cost the contractor over 45% of the logging rate achieved, and therefore makes this method unattractive to the contractor unless a premium on top of the logging rate can be negotiated.

4.1.3 Applicability of Shovel Logging

It was made apparent from the production curves and unit costs with distance that Shovel logging within medium sloped New Zealand terrain is very favorable at short distances from landing and roadside processing, however at greater distances both of the machine productivity and extraction unit cost (Table 3) become unattractive for the contractor required to achieve a certain production level and logging rate.

The shovel employed a Serpentine pattern for yarding stems on the flatter underside of the skidder trail (Figure 2); which proved to work well given the setting shape and terrain (<30%). In steeper country the best shovel pattern was seen on Day 2 to keep the wood flow moving in a direction parallel to the contours of the hillside. The uneven terrain provided certain points where the operator could shovel from, hence a zigzag pattern down the hill developed (Figure 3) allowing the wood to be moved to a point where it could accessed by the yarder.

4.2 Validity of Results

The results given from data collected are dependent on the terrain and system that was apparent on each day; they are therefore regarded as separate case studies. The data on *Day 1* was largely limited to machine loaded times and lacks data on time related to unloaded swing, motion and delays. In order to give the results for *Day 1* more cycles are needed. However there was enough unloaded data collected to find an adequate correlation for the machines productivity, and this is shown in Table 3. The correlation (R^2 value) between production and loaded volume is seen in Figure 8 and Figure 9 to be low is both case studies as the working conditions vary significantly for each cycle and it is difficult to have the same swing every time, however they both show an overall strong increasing relationship.

4.3 Future Research

Future research that would complement this study of shovel logging would include:

- Interaction between slope angle and machine effectiveness;
- The incorporation of a winch or belay line to gain access to steep terrain which logging is not currently being carried out in this manner, and which machine movements would best extract wood from a steep slope/gully;
- Interaction of machines and environmental disturbance on steep New Zealand terrain susceptible to erosion and landslides.

5. Acknowledgements

The Author would like to acknowledge Blakely Pacific Ltd and City Forests Ltd for allowing access onsite and the contractors for their cooperation and help for collecting data. Also much appreciated is the assistance given by Barry Wells, Graeme Martin and Associate Professors Rien Visser and Tom Gallagher.

6. Works Cited

Volvo Construction Equipment. (2004, March). Retrieved September 2013, from Volvo: http://www.volvoce.com/constructionequipment/global/en-au/products/trackedforestrycarriers/FC3329C/Pages/specifications.aspx

Fisher, James. (1986). (A). *SHOVEL LOGGING: Cost Effective System Gains Ground.* Washington: Weyerhaeuser.

Fisher, Jim. (1986). (B). *Logging With A Hydraulic Excavator.*

Flock, Rick F. (1988). *Shovel Logging and Soil Compaction: A Case Study.* Corvallis: Oregon State University.

Hemphill, Dallas C. (1986). *Shovel Logging.* New Zealand: Logging Industry Research Association.

Sloan, Hank. (1992). *Study on "Shovel Logging in Virginia's Mountains".* Ashburn: Grindstone Engineering.

Visser, Rien. (2013). *Benchmarking to Improve Harvesting Cost and Productivity: 2012 Update.* Rotorua: Future Forests Research.

Wang Jinxin, Long Charlie., McNeel, Joe. (2004). Production and Cost Analysis of a Feller-Buncher and Skidder in Central Applalachian Hardwood Forests. *Forest Products Journal Vol. 54, No 12*, 159-167.

7. Appendices

7.1 Log volume sample

Day 1:

Stem number	Length	Size Sample: Taper Diameter (m) 1	2	3	4	Vol. (m)
1	22	0.33	0.21	0.15	0.08	0.72
2	21	0.38	0.3	0.26	0.2	1.37
3	24	0.5	0.34	0.26	0.15	2.01
4	22	0.38	0.26	0.17	0.14	1.03
5	9	0.3	0.23	0.17	0.18	0.34
6	25	0.47	0.34	0.27	0.1	1.99
7	18	0.26	0.2	0.14	0.08	0.46
8	23	0.42	0.34	0.265	0.1	1.68
9	17	0.23	0.16	0.11	0.05	0.29
10	13.5	0.28	0.21	0.17	0.14	0.43
11	23	0.5	0.34	0.27	0.18	1.99
12	25.2	0.44	0.32	0.26	0.1	1.79
13	26	0.59	0.46	0.3	0.18	3.35
14	24	0.4	0.24	0.21	0.12	1.46
15	12.8	0.44	0.32	0.29	0.22	1.03
16	24	0.56	0.48	0.34	0.13	3.21
17	16.5	0.25	0.19	0.15	0.1	0.41
18	25.5	0.49	0.45	0.28	0.2	2.81

Day 2:

Stem number	Length	Size Sample: Diameter (m) 1	2	3	4	Vol. (m)
1	26	0.74	0.38	0.3125	0.145	3.58
2	17.3	0.47	0.425	0.36	0.275	2.08
3	17.4	0.69	0.44	0.385	0.355	2.93
4	23.5	0.67	0.495	0.435	0.305	4.34
5	14.3	0.665	0.495	0.44	0.38	2.74
6	15	0.72	0.5	0.47	0.38	3.15
7	15.8	0.425	0.32	0.315	0.245	1.33
8	7.1	0.405	0.34	0.29	0.23	0.57
9	12	0.54	0.52	0.305	0.25	1.70
10	27	0.59	0.415	0.31	0.17	3.23
11	20.6	0.62	0.5	0.415	0.34	3.63
12	21	0.57	0.46	0.375	0.265	3.02
13	25.2	0.56	0.355	0.295	0.17	2.54
14	14.9	0.66	0.5	0.45	0.35	2.85
15	14.5	0.71	0.55	0.475	0.33	3.17
16	26.6	0.495	0.4	0.335	0.245	2.96
17	15.8	0.385	0.26	0.15	0.08	0.69
18	8.2	0.68	0.5		3*10m	2.79

7.2 LIRO Costing Model

MACHINE COSTING		
Machine - Function		**Loader**
Type		CAT 330 & grapple
Power (kw)		160
Year purchased		2008
Machine Life	Workdays per year	230
	Productive Hours per day	8
	Hours per year	1840
	Hours to be owned?	20000
	Machine Life (yrs)	**10.9**
Fixed costs		
Capital Cost	Current new price	$410,000
	Resale value (as a % of cost)	10%
	Current used price (after hours to be owned)	$41,000
	Tyre/Tracks life (hrs) *	5,000
	New tyre/tracks price	$40,000
	Annual depreciation	$30,268
	Depreciation ($/Workday)	**$ 131.60**
Interest	Proportion of ACI as loan	75%
	Proportion of ACI as owners equity	25%
	Loan interest rate	8.50%
	Owners interest rate	7.00%
	Weighted interest rate	8.13%
	Average capital invested	$242,474
	Interest ($/Workday)	**$ 85.66**
Insurance	Insurance Rate as a Percentage of ACI	2.0%
	Insurance ($/Workday)	**$ 21.08**
Total Fixed Costs ($/Workday)		**$ 238.34**
Running costs		
Fuel	Fuel price ($ per litre)	$ 1.59
	Fuel Usage litres/kW/hr	0.15
	Fuel Cost ($/Workday)	**$ 305.28**
Oil	Oil as a % of Fuel	15%
	Oil Costs ($/Workday)	**$ 45.79**
R+M	R + M as a % of depreciation	60%
	Repairs and Maintenance	**$ 78.96**
	Tyres/Tracks	**$ 64.00**
	Rigging	**$0.00**
Total Running Costs ($/Workday)		**$494.03**
Total Machine Rate ($/Workday)		**$732.37**

Total Machine Rate Per Hour	**$ 91.55**

Total Machine + Labour Rate Per Hour		
	SMH	$ 122.86
	PMH	$ 198.16

COST VARIABLES		
Days per year		-
Loan Interest Rate		8.50%
Owner's Interest Rate		7.00%
Insurance		2.00%
Diesel Price		$ 1.59
Petrol Price		$ 2.20
RUC/1,000km		$ 39.13

4. Average annual cost of worker	days/yr	$/day	$ / hr	Total
Normal time	245	$ 225.00	25.00	$ 55,125.00
Annual bonus				
Overtime	230			$ -
4.1 Total Gross Earnings			total	$ 55,125.00
4.2 Plus annual holidays			20.00	$ 4,500.00
4.3 Plus ACC levy (as $per $100)			6.71	$ 4,000.84
4.4 Kiwi Saver costs		%	2.00%	$ 1,192.50
Annual cost of all workers (4.1+4.2+4.3+4.4) =				$ 64,818.34
Plus non-taxable allowances (Total 3.)			=	$ -
Total Annual Labour Cost			=	**$ 64,818.34**
Labour cost per workday			=	**$ 281.82**
Average daily cost per worker				**$ 281.82**
Average SMH cost per worker				**$ 31.31**