The Effect of Landing Size on Operational Delays for New Zealand

Harvest Operations

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Abstract

Landings are an integral part of New Zealand Harvest operations where extracted trees are processed into logs and loaded out onto trucks. Forest owners need to balance the cost and environmental considerations when designing and constructing landings, with the productivity and safety of the harvesting crew that will use the landing.

The objective of this study is to gain a greater understanding of landing size and how they affect forest harvest operations. This study investigates the relationship between landing size and processing delays. A time study was carried out for ten harvest operations predominantly in the lower North Island. The time study recorded all delays on the processing task of measuring and cutting stems into logs. The delays were then categorised so that only processing delays that are influenced by the size of the landing remained. These processing delays were then expressed per m^3 and used as the response variable in regression analysis to test their correlation against landing size and a range of other predictor variables.

A very strong, linear relationship between processing delays per m^3 and actual landing size was found. This indicates that harvest operations on smaller landings exhibited higher delays per m^3 than those on larger landings. Loading of the deck was the most significant processing delay; this is a direct result of not having enough room for surge piles as delimbing was not able to be carried out during loader downtime. The significance of the relationships developed in this study can help forest owners realise the implications of building landings that are too small for the intended purpose. Not only will small landings affect productivity, but have the potential to financially affect the forest owner also.

Key Words: Landings, landing size, harvesting, operational delays, processing.

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1. Introduction

A forest landing (also referred to as a deck, skid site, or skid) can be typically defined as an area within a forest where stems are extracted too, processed, stored and then loaded out to market (Visser, Spinelli, & Magagnotti, 2010). A landing is usually cleared of topsoil and has obstacles such as tree stumps removed. A typical New Zealand cable logging operation landing is shown in figure 1. Landings are an important piece of infrastructure for New Zealand harvest operations. As of 2011 New Zealand's annual forest removals were above 21 million m^3 (FOA, 2012), of which almost all is harvested using a log-length system. With a log-length harvesting system all trees are felled and extracted as whole stems to the landing. The stems are then processed into several different log sorts. This processing task requires enough room to lay out a 'deck' which is a group of parallel stems to be measured and cut into logs by either workers with chainsaws or a mechanised processor on an excavator base. A loader has to be able to manoeuvre between this deck and the log stacks. The log stacks typically consume the most space on a landing as there is a different stack for every log grade. An efficiently sized landing will have sufficient room for the processing task to continue whilst a log truck is being loaded to transfer logs from the landing to market.

Figure 1 - A typical New Zealand woodlot cable logging landing.

The alternative to this log-length harvest system is methods such as cut-to-length (CTL) harvesting in which trees are felled and processed into logs at the stump. With CTL the only task that does not take place at the stump is loading which is typically done at the roadside which requires either a very small landing or no landing at all. This is a popular harvest system method in European countries where environmental restrictions severely limit earthmoving operations.

Depending on Regional Council plan requirements large forestry earthmoving operations in New Zealand typically require resource consent. The restrictions of these resource consents take into account the environmental impacts of earthworks with the main focus being around erosion control. Large landings, particularly on steep terrain, require high volumes of soil to be disturbed and moved. In certain situations the location and/or size of a landing may be restricted to comply with resource consent requirements.

There is a conflicting argument as to what size landings should be. Harvesting contractors typically want landings as large as possible. Through experience they understand the implications that landing size has on the productivity of their operation and the health and safety of their employees. The frequency of serious and fatal accidents is particularly high in the forest industry. The latest fatal accident that took place on the 19th of July, 2013 occurred on a forest landing whilst a truck was being loaded. Typically fatal accidents occur during breaking out and tree felling tasks but many serious injuries occur from processing tasks on the landing. The recent high accident rate has prompted a full review of the industry by the Ministry of Business Innovation and Employment. Forest owners and forest management companies want to design landings as small as necessary to reduce infrastructure costs. Landings are expensive to construct, with a typical construction cost for a New Zealand forest landing ranging between $4000 and $7000 with some large complicated landings above $10,000 (Visser, Spinelli, Saathof, & Fairbrother, 2009)

Operational delays are any activity that is necessary to the harvest operation but is not part of the primary function that is being investigated. For example, in a study investigating hauler production, waiting for the choker setters would be an operational delay. For production levels to be as high as possible, operational delays need to be

minimised. Operational delays do not include mechanical delays such as breakdowns or social delays.

There have been studies on what factors determine landing size, but very little research has been carried out on the relationship between landing size and production. This study will try to obtain a greater understanding of this relationship between landing size and production by focusing on operational delays.

2. Literature Review

2.1 Forest landings

In New Zealand, forest landings are typically designed by forest managers and built by an earthmoving and/or roading contractor. Basic characteristics and expectations of a landing are that it is able to provide the space required to process stems into logs. They must be large enough to accommodate the harvest system equipment and log stacks all while providing a safe work environment for the crew (Liley, 1983; Studier & Binkley, 1974).

The size and specification of the landing is typically prescribed by the forest manager and the harvest contractor often has little input in landing design (Raymond, 1987). This often results in landings being undersized as forest managers try to reduce construction costs. These small landings generally make log handling less economical. Soil type can also affect construction costs as clay type soils are difficult and more expensive to work. This places more pressure to restrict landing size (Liley, 1983).

Harvest contractors feel very strongly about small landings because when landing size is limited there is not sufficient area for the loader to manoeuvre and workers and equipment are placed at risk (Conway, 1976; OR-OSHA, N/A; Studier & Binkley, 1974). In New Zealand, government approved codes of practice for forestry state that work on a landing shall only proceed when there is enough room for stems to be landed safely and adequate area to park vehicles. It also mentions that all workers must operate at a safe distance from any working machinery but does not specify what this distance is (MBIE, 2012).

Over time the average landing size in New Zealand has increased significantly. A study by Raymond (1987) found the average landing size in 1987 to be 1900 m^2. In 2010 this study was repeated and the average landing size was found to be 3900 m^2 (Visser et al., 2010). This significant change and size appeared to be a result of the increased productivity of harvest operations and an increase in the number of log sorts cut. These two studies also investigated the main factors that influence landing size and both produced similar results. Raymond (1987) found that landing size increases with an increasing number of log sorts being cut, daily production and whether the loading was

carried out by a wheeled or knuckle-boom loader. The results of the 2010 study concluded the same factors influenced landing size except, instead of loader type as a variable it showed whether the landing was in use or not was a significant predictor of landing size (Visser et al., 2010). These changes in variables were put down to the fact that the type of loader used is generally explained by daily production, as at this point in time typically only high production harvest operations use wheeled loaders. Whether the landing was currently in use was a significant factor as landings generally expand during the time of operation.

A study by Hemphill (1988) of 15 cable logging operations in the Pacific Northwest of the United States produced a very small mean landing size of 445 m^2. The study investigated delays of the log loader and concluded that the main cause of delays was the productivity of the hauler not being able to keep up with the processing operation. Processing delays in particular were not investigated in this study. These delays caused by hauler productivity are not directly related to landing size and show that for productivity to be restricted by landing size there has to be a bottleneck at the landing, not extraction. On one of the particularly small landings in the study a significant delay of 0.49 minutes per turn was observed due to there being insufficient room for the hauler to land stems, requiring the loader to hold each stem for unhooking. This delay is a direct result of landing size.

Building exceptionally large landings is not the right answer. Doing so will incur unnecessary construction costs and there are also other negative effects of large landings (Studier & Binkley, 1974). Landing construction can cause substantial soil disruption (Liley, 1983) which is proving to be more and more of an issue in New Zealand, especially in environmentally critical sites. Landing construction causes compaction of the soil which results in soil that is often not suitable for growing trees. This must be weighed against the reduction in logging costs from a bigger landing.

2.2 Log Processing

Log processing is one of the most important tasks of a forest harvest operation and can greatly affect the value recovery of a forest (McKerchar, 1987). Processing is the main task that is undertaken on a landing and consequently requires some specific spatial landing characteristics. In the last twenty years New Zealand has seen a significant increase in the number of log sorts to be cut and this has caused a number of issues for harvest contractors (Cass, Baker, & Greene, 2009). The task of processing is made more difficult when several log sorts are to be cut, particularly if the landing is small (McKerchar, 1987). The increased work required by harvest contractors to process, sort, store and load these extra log sorts has reduced harvest productivity and returns to the contractors (Cass et al., 2009). Studies have also shown a significant increase in log-making and grading errors with an increased number of log sorts (Parker, Park, Clement, & Gibbons, 1995).

2.3 Time study

Time studies are a particularly useful tool in forest research. They are undertaken for a number of reasons with the most common being a means to investigate the factors that can influence productivity, and therefore the costs and viability of an operation. Typically harvesting time studies focus on the impact of stand and terrain variables on productivity (Visser et al., 2009) and very few have investigated the impact of landing size as a variable. There are several limitations that come with the implementation of time studies in forest harvesting. Bergstrand (1987) indicated that operator performance can result in a 20-50% variation in machine productivity which produces a variable that is very difficult to measure. It is noted that to overcome this variation in operator differences that samples sizes of around 400 operators should be used, a number that is often unpractical and uneconomical to acquire.

The large amount of variables in forest harvest systems can make models complicated and inaccurate. Other studies have indicated that it is best to simplify the over-abundance of predictive variables in harvesting studies by selecting the dominant and most significant factors in the study and then again when evaluating the data by assuming basic relationships to the response variable (Visser et al., 2009).

3. Objective

The goal of this study is to obtain a greater understanding of landing sizes and how they affect forest harvest operations. If a significant trend is produced between landing size and operational delays the data will help forest owners realise the constraints applied to their contractors when they operate on landings smaller than they require.

4. Methodology

The study observed ten motor manual forestry harvest operations in both the North and South Islands. In this case motor manual refers to the processing of the stems on the landing being cut by chainsaw. All ten operations were clearfell in radiata pine plantations mostly in woodlots and medium sized forests. Only motor manual operations were used as the processing delays of mechanised systems are less consistent and harder to measure over a short time span. A range of ground based and cable logging systems were used (Table 1) as these different harvest systems often have different requirements for landing sizes and shape. In order to compare the effects of landing size on the harvest operations a classic time study was carried out that focussed on processing delays.

Table 1 – Location and harvest system of the ten logging crews in the study

Logging crew	Extraction	Location
A	Ground based	Wellington, North Island
B	Cable logging	Otaki, North Island
C	Cable logging	Taranaki, North Island
D	Ground based	Pauatahanui, North Island
E	Cable logging	Pauatahanui, North Island
F	Ground based	Bulls, North Island
G	Ground based	Levin, North Island
H	Ground based	Burnham, South Island
I	Ground based	Rangiora, South Island
J	Cable logging	Levin, North Island

4.1 Landing and operation measurement

The area of each landing was calculated using a *Garmin GPSmap 60 CSx* hand-held GPS. The area defined as the landing was any constructed flat surface where the processing and loading operations take place. Often whole stems and surge piles are laid out on the cutover next to a constructed landing; these will not be included in the landing area. Where a road passes through a landing it will be included as part of the landing. If a road passes alongside a landing it will be excluded from the landing area. Landing areas were calculated twice, and if the second area deviated significantly from the first it was calculated again. This definition of landing area was used to be consistent with previous studies (Visser et al., 2010).

The map output of each landing area was exported to calculate the landing shape ratio. This ratio is the distance of the length of the landing divided by the distance perpendicular to the length. For example a 60m x 40m landing produces a landing shape ratio of 1.5:1.

The numbers of log sorts currently being cut were recorded for each operation. A log sort is defined as a particular log grade and length. For example P35 4.9m, 5.5m and 6.1m are three different log sorts. This was measured by talking to the log maker and asking what sorts he is currently cutting as often log sorts on the cut plan are not produced due to log stack size restrictions.

An average production in loads per day was calculated for each operation. This was done by looking through docket books for the previous week's delivered loads whilst on the landing is question. If the crew was relatively new to the landing and inventory had not been built up yet then production would not be calculated at this time because there would be a shortfall as fewer loads are delivered in the first week of working on a landing whilst inventory is built up. When looking through the previous week's delivered loads it was made sure that there was no significant event that could affect the average production figure.

The number of workers or "skiddies" was recorded, as this will greatly affect the processing time of each deck. This included both log makers and chainsaw operators. When a loader operator also acts as a log maker or chainsaw operator he/she was also included in this number of workers.

Harvest systems vary a lot in the type and number of machines and workers they have. They also vary in the number of log sorts and daily production. Just comparing the actual landing size of the different landings will not provide detailed data on how each operation is constrained, as a low production crew cutting only a few log sorts will be less constrained than a high production crew on the same sized landing. To solve this issue, as well as actual landing size, a relative landing size was calculated. This relative landing size is the proportion that the actual landing size is of the national average landing size for that operation. The regression equation below was developed in a study which investigated what landing variables determine landing size in New Zealand (Visser et al., 2010) and was used to calculate the national average landing size for each of the ten landings in this study.

Eq 1: $National\ average\ landing\ size\ (m^2) = 390 + 560 \times a + 173 \times b + 3.5 \times c$

Where: $a = Landing\ age\ (0 = new\ 1 = in\ use, 2 = old),$ $b = Number\ of\ log\ sorts\ (\#),$
$c = Daily\ production\ (tonnes)$

4.2 Time study

An elemental time study was used to compare any delays on the processing operation and the time of processing itself. A simple stopwatch was used to record each delay rounded to 30 seconds. The total time for each study ranged from two to six hours. Delays were grouped into six categories with the processing delays influenced by landing size being the focus of this study.

Processing delays influenced by landing size–

- Loading Deck – Delimbing and loading of stems onto deck.
- Fleeting – Fleeting cut logs from deck into log stacks.
- Other – Any other delay to processing that is deemed to be influenced by the size of the landing.

Delays not influenced by landing size –

- Social delays – Lunch breaks, stopping to talk etc.
- Technical delays – Mechanical delays, breakdowns.
- Other – Other delays to processing that are not influenced by the size of the landing, the most common being no wood to process and truck loading.

Truck loading is an important element of a processing operation, but due to the inconsistency of truck arrival times, any delays resulting from truck loading were recorded in the delays not influenced by landing size 'other' category. Delimbing stems is an important element of a processing operation. All harvest crews in the study use a *Harvestech 3000* hydraulic delimber. Due to size constraints for surge piles some operators delimb each stem as it is loaded onto the deck and some delimb surge piles during downtime. For the purpose of this study the delimbing element is recorded as part of the loading deck element because of the difficulty in separating delimbing and loading deck delays when stems are delimbed as they are loaded.

The time each deck takes to process was recorded. A 'deck' is defined as a group of stems laid out (typically on bearer logs) to be processed into logs. This includes measuring the stems and the bucking of stems into logs. The number of stems per deck was recorded along with the average piece size per stem for the particular landing which was obtained from inventory records from the forest owner. An example of a typical deck used in New Zealand motor manual operations is illustrated in figure 2.

Figure 2 - Example of the processing area of a landing known as a 'Deck'.

4.3 Survey

In order to get some useful feedback from harvest contractors a simple survey of what they like and do not like about their current landing was carried out. This will provide important information on what harvest contractors believe should be considered during landing design (Appendix 1).

4.4 Analysis

Delays were broken down so that processing delays could be expressed per volume produced. Social delays, non-processing delays and processing time were all subtracted from the total measured time to produce processing delays for each of the ten crews. By multiplying the stems produced by the average piece size an estimated volume per m^3 is given. Processing delays were then divided by estimated volume per m^3 to give processing delays per m^3.

These processing delays per m^3 were then used as response variables with actual landing size, relative landing size, number of log sorts, number of workers, landing shape and daily production as predictor variables. Regression analysis was carried out in the statistical package *R* and in *Microsoft Excel*.

The statistical significance of the independent variables was reported by the p-value. If a landing variable was significant ($p<0.05$) then its coefficient represents a statistically significant correlation between that variable and processing delays.

The coefficient of determination, R^2, is a measure of the percentage of variation that has been explained by the regression equation. The remaining variation ($1 - R^2$) is unexplained variation. In this study the R^2 value explains how much of the variation in the Y variable (processing delays per m^3) is explained by the X variable (predictor variable). The multiple R^2 value is used when only one predictor variable is used in a regression model

5. Results

5.1 Landing measurement

Table 2 displays the specifications for the landings of the ten logging crews in the study. The average landing size was 1622m^2 with a large range shown by the 95th percentile of 2341m^2 and 5th percentile of 754m^2. This mean landing size is significantly lower than other studies that produced a mean New Zealand landing size of 3900 m^2 (Visser et al., 2010). The standard deviation of 640m^2 shows a large amount of variation in landing size. There is also a large amount of variation in landing shape shown by the relatively high standard deviation and wide range between the 95th and 5th percentile values. The mean landing shape is 2.0:1 with all landings except that of crew E being considered rectangular/elongated. This matches initial results of other studies on landing shape (Visser et al., 2010). Crew F's landing is a rectangle with a ratio of 3.74:1. This is predominantly caused by space restrictions resulting from a steep slope of one side of the landing and a fence that cannot be removed on the opposite side.

Table 2 – Harvest system and landing variables of each of the ten logging crews

Logging crew	Landing size (m^2)	Loads per day	Number of Log Sorts	Number of Workers	Landing shape ratio
A	770	2	9	1	2.1 : 1
B	1650	3.5	12	2	2.42 : 1
C	2220	6	20	3	1.96 : 1
D	2120	4	13	2	1.33 : 1
E	2020	4	10	2	1.11 : 1
F	1330	4	18	2	3.75 : 1
G	910	3	13	3	1.46 : 1
H	2020	4	11	2	2.83 : 1
I	740	3.5	7	2	1.49 : 1
J	2440	4	17	2	1.91 : 1
Mean	**1622**	**3.8**	**13**	**2.1**	**2.04** : 1
Std deviation	**640**	**1.0**	**4.2**	**0.6**	**0.8** : 1
95th percentile	**2341**	**5.1**	**19.1**	**3**	**3.34** : 1
5th percentile	**754**	**2.5**	**7.9**	**1.45**	**1.21** : 1

The number of log sorts cut on each landing is also varied with the two logging crews with landings under 800m^2 being the only ones cutting less than ten log sorts. Logging

Crew F is on one of the smaller landings but is cutting the second highest number of log sorts; this indicates that some crews may be very restricted for space on their landing.

A regression of landing size against daily production produces an R^2 value of 0.49 with a significant p-value of 0.025. This shows that the logging crews on the smaller landings have a lower daily production than those on larger landings. This is consistent with results of other studies by (Hemphill, 1988; Raymond, 1987; Visser et al., 2010).

5.2 Relative landing size

The regression equation for the New Zealand national average landing size (Equation 1) was used to calculate the national average equivalent for each of the ten landings in the study (Table 3). This equation uses the coefficients of landing age (which in this case is always 1, as the landings are all in use), the number of log sorts currently being cut and a daily production in loads per day.

By dividing this actual landing size by the national average landing size a proportional or relative landing size is produced. This allows comparison of the different levels of landing size constraint.

Table 3 – Actual, national average and relative landing sizes for each of the ten logging crews

Logging crew	Actual landing size (m²)	National Average (m²)	Relative landing Size
A	770	2514	31%
B	1650	3038	54%
C	2220	4431	50%
D	2120	3213	66%
E	2020	2694	75%
F	1330	4078	33%
G	910	3209	28%
H	2020	2867	70%
I	740	2173	34%
J	2440	3905	62%
Mean	**1622**	**3212**	**50%**
Std dev	**640**	**723**	**18%**
95ᵗʰ percentile	**2341**	**4272**	**73%**
5ᵗʰ percentile	**754**	**2327**	**29%**

5.3 Operational delays

The recorded results of the time study are shown in Table 4. The number of stems produced during each study was recorded and then multiplied by the average piece size. This allowed the estimation of volume produced in m^3.

The total minute's column shows the total recorded time for each logging crew. When social delays and non-processing delays are subtracted from the total time the effective scheduled processing time (ESPT) remains. When processing delays are subtracted from this ESPT the actual processing time remains. Processing delays are all processing related delays that are deemed to be affected by landing size.

Table 4 – Breakdown of recorded delays, separated processing delays and volume data measured from the ten motor manual harvest operations.

Logging crew	Stems processed	Avg Piece size (m^3)	Est volume prod (m^3)	Total mins	Social delays (mins)	Non-processing delays (mins)	ESPT (mins)	Processing delays (mins)	Processing time (mins)
A	19.0	1.8	34	222	8	46	169	86	84
B	29.0	2.2	64	318	33	63	223	138	85
C	59.0	2.5	148	359	68	64	227	105	123
D	40.5	2.2	89	292	71	14	208	100	108
E	23.5	1.8	42	146	0	0	146	91	55
F	21.0	1.6	35	210	49	16	145	82	63
G	14.0	1.6	22	126	34	0	93	70	23
H	46.0	1.0	46	167	2	0	165	78	88
I	30.0	0.9	27	252	49	93	111	64	47
J	34.0	1.4	48	127	0	50	77	23	54

Table 5 shows the categorised processing delays. These are expressed as both delays per ESPT and delays per m^3. Delays per m^3 is calculated by dividing processing delays by the estimated volume produced in m^3 and will be the main focus of analysis. The high standard deviation and wide range of processing delays per m^3 shows a large amount of variation in the delays recorded. This level of variation is also present in the individual loading deck and fleeting delays. The high variation in the loading deck delays is most likely attributed to the fact that some logging crews were forced to delimb individual stems as they loading them onto the deck which increased overall loading deck delays. The crews with smaller loading deck delays delimbed into surge piles whist the loader was not needed for other tasks. As expected the mean fleeting time is longer than the loading deck time which is due to individual logs being handled.

Table 5 – Individual and total processing delays per m^3 and ESPT.

Logging crew	Processing delays per ESPT (mins)	Processing delays per m³ (mins)	Loading deck delays per m³ (mins)	Fleeting delays per m³ (mins)	Processing time per m³ (mins)
A	0.51	2.50	1.24	0.53	2.44
B	0.62	2.16	0.83	0.64	1.32
C	0.46	0.71	0.31	0.40	0.83
D	0.48	1.12	0.45	0.57	1.21
E	0.62	2.14	1.24	0.77	1.30
F	0.57	2.44	0.70	1.74	1.88
G	0.76	3.13	1.21	0.67	1.00
H	0.47	1.68	0.61	1.08	1.90
I	0.57	2.35	0.91	1.44	1.74
J	0.30	0.48	0.19	0.26	1.13
Mean	27.27	1.87	0.77	0.81	1.48
Std dev	9.59	0.85	0.39	0.47	0.50
95th percentile	0.70	2.84	1.24	1.61	2.20
5th percentile	0.37	0.58	0.24	0.33	0.91

5.4 Statistical investigation

An all subsets regression function was run in '*R*' using a range of predictor variables against the response of processing delays per m^3. This function tries all models with a range of predictors in all possible combinations. The predictor variables used were –

- Actual landing size
- Relative landing size
- Landing shape ratio
- Number of log sorts cut
- Number of workers
- Daily production

This all subsets regression produces the output shown in figure 3, where each column is a different model with the predictor variables on the X axis. The lower the Cp value is on the Y-axis the more variation is explained by the model. An all subsets regression would usually be used with a large sample size, however this study only has a sample size of ten.
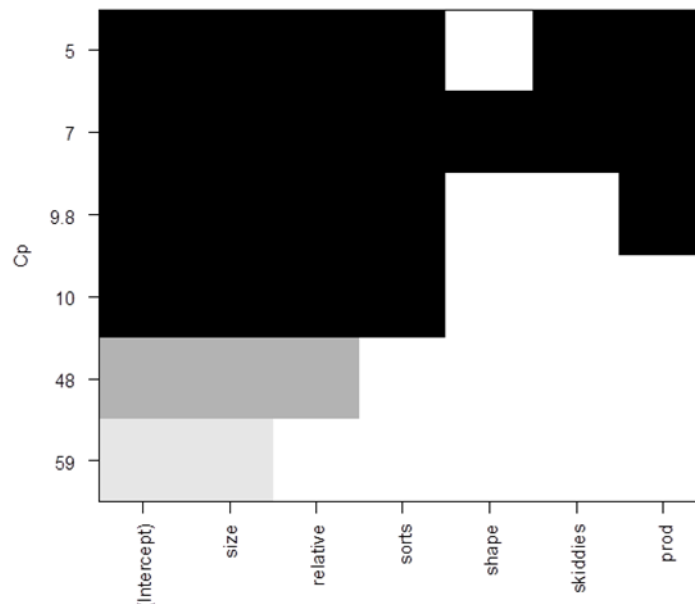

Figure 3 – All subsets regression Cp plot produced in R

To avoid unreliable statistics only the top two predictors from the Cp plot were further analysed as predictor variables in a regression model against processing delays. This regression produced the following model:

$$Processing\ delays = \ 3.455 + \ -0.001\ \times a + 2.14 \times b$$

$$a = Actual\ landing\ size\ (m^2), \qquad b = Relative\ landing\ size\ (m^2)$$

This Linear model used actual landing size and relative landing size predictor variables which together explain 72% of the variability in operational delays per m^3 with a significant p-value of 0.005. The average error around this prediction is rather high given the residual standard error of 0.45 minutes when the mean delay is 1.87 minutes. This error would be too high if the model was being created for use as a prediction function, however for the purpose of investigating a relationship it still shows a significant trend.

5.5 Delays by relative landing size

Figure 4 shows the total landing size affected processing delays per m^3 against the relative landing size. This relationship shows a reasonable trend in that processing delays increase with a decrease in relative landing size. The equation for this regression is:

$$Processing\ delays = -2.86 \times Relative\ landing\ size + 3.31$$

The correlation of this regression produces an R^2 value of 0.36 and a p-value of 0.067 indicating that there is a trend but it is not statistically significant. It is possible that there are compounding errors in the equation used to calculate the national average and relative landing sizes as when it was developed it only accounted for around 50% of the variation in landing size. There is a gap in relative landing sizes recorded between 35% and 50% of the national average. More landings in this range could help strengthen the trend.
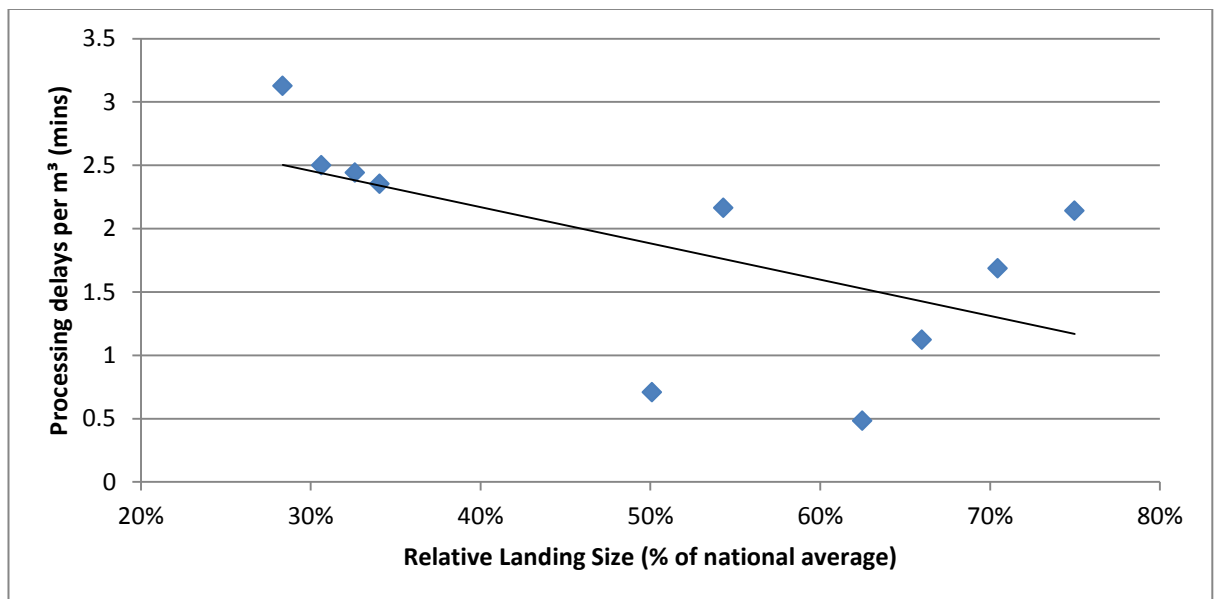

Figure 4 – Processing delays by relative landing size

5.5 Delays by actual landing size

It is probable that landings for larger and more productive operations are designed to accommodate the production and size of the operation. Processing delays per m^3 were also regressed against the actual landing size. This regression is shown in Figure 5. There is a very strong linear trend that supports the trend in Figure 4. The equation for the regression is:

$$Processing\ delays = -0.001 \times Actual\ landing\ size + 3.71$$

An R^2 value of 0.72 shows that 72% of the variation in delays is explained by the actual landing size and that the relationship is statistically significant ($p<0.005$)
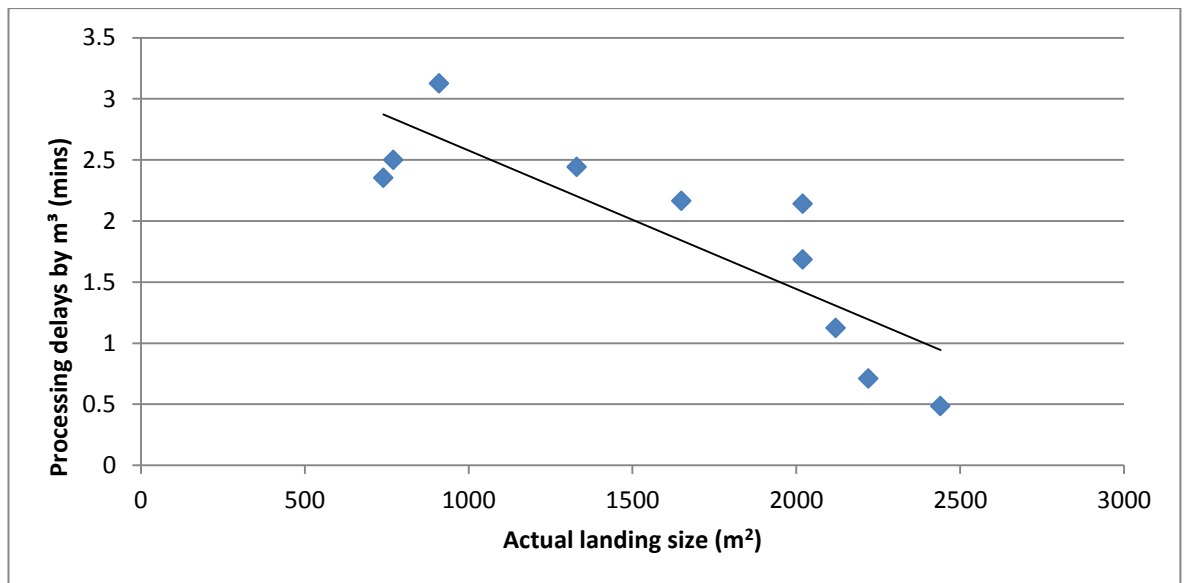

Figure 5 – Total delays by actual landing size

5.6 Components of processing delays

Figures 6 and 7 show processing delays by the individual categories of loading deck and fleeting delays regressed against actual landing size. Both types of processing delays show a decreasing trend with increasing landing size. Fleeting delays show the least significant trend with an R^2 value of 0.20. Loading deck delays exhibit the highest amount of variation explained by actual landing size with an R^2 value of 0.52. This is most likely due to the fact that crews on smaller landings had to delimb each stem as it was loaded, which increased their loading deck delays. The regression of 'other' delays were also regressed against actual landing size which produced an R^2 of 0.29 however four of the ten logging crews produced no 'other' delays and the trend is mainly caused by one outlier of a delay above 1.2 minutes.
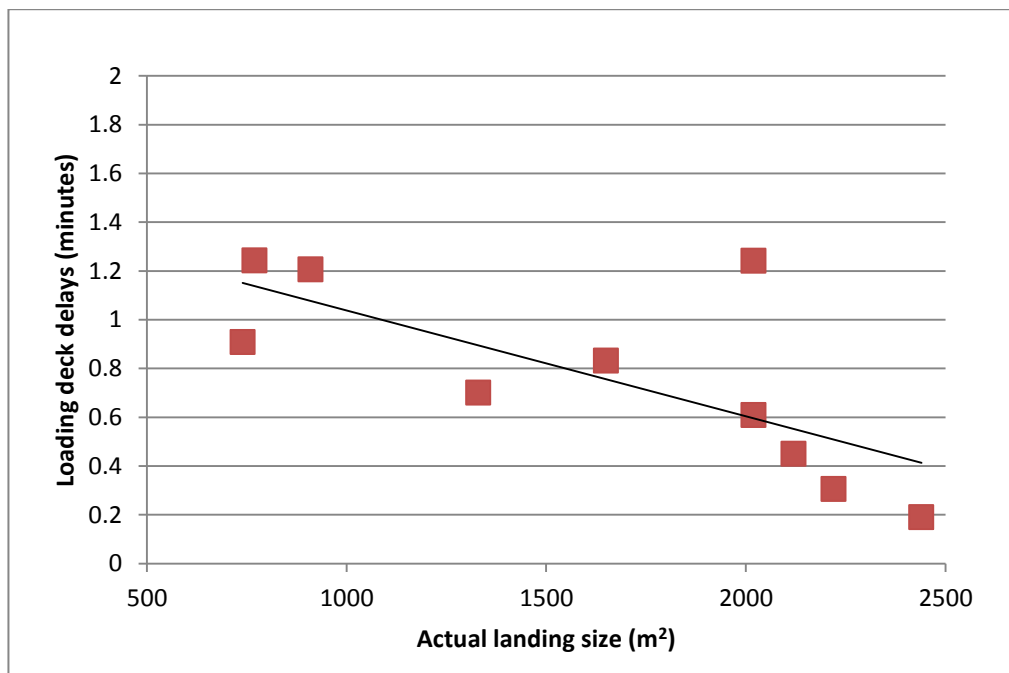

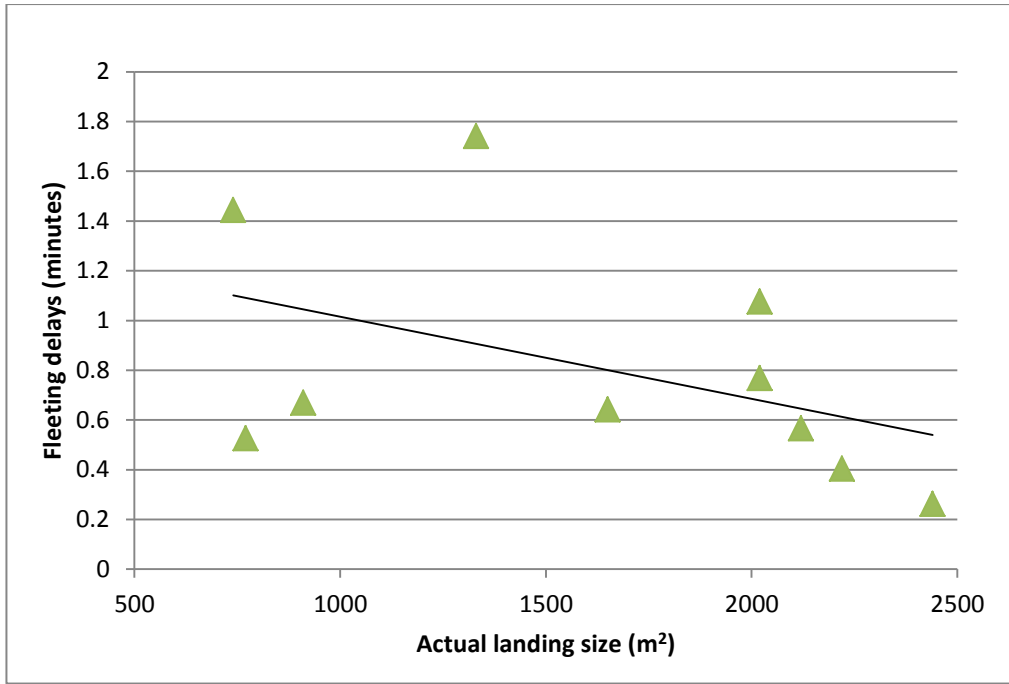**Figure 6 – Loading deck delays by actual landing size**

Figure 7 - Fleeting delays by actual landing size

5.7 Processing time

With a mean of 1.48 m^3 per minute and a standard deviation of 0.50 m^3 per minute the processing time per m^3 has less variation than processing delays. When processing time per m^3 is regressed against actual landing size (Figure 8) there appears to be somewhat of a linear trend but the low R^2 of 0.29 and a p-value of 0.11 suggest no significant relationship. This is because the processing task of actually measuring and cutting logs is not affected by landing size as much as other tasks. It is more dependent on the number of workers carrying out the processing operation and the skill of these workers. The slight trend shown in Figure 8 is most likely due to the economies of scale as on large landings more stems can be processed on each deck.
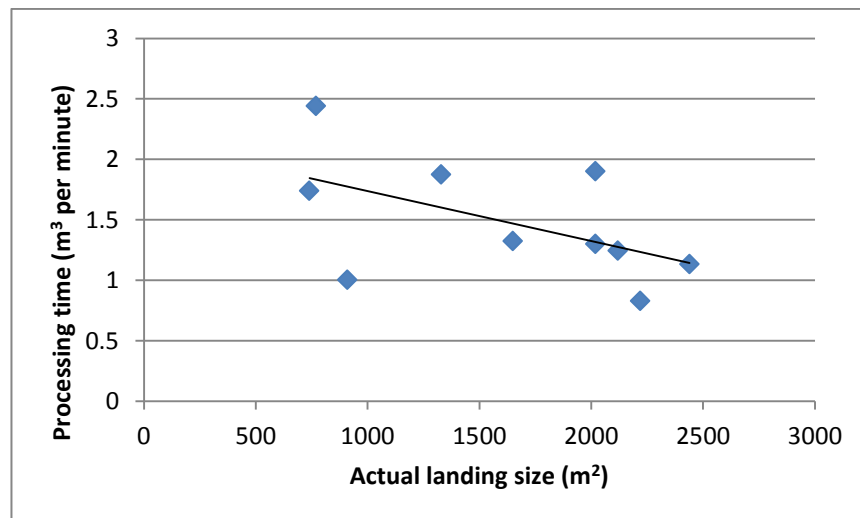

Figure 8 – Processing time per estimated volume produced in m^3

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5.8 Survey

The short survey was carried out to obtain information on what logging contractors positively or negatively valued about their current landings. Figure 9 shows how many contractors out of the total ten valued the particular landing characteristic. Size was the first thing that all ten or the contractors mentioned, six thought their landing was too small and four thought their landings size was adequate. All ten contractors believed that their operations suffer if they do not have an adequately sized landing. Five of the six contractors who believed their landings were too small also said they have associated health and safety risks as the workers are often working close to machines. This restricted space slows their operations down because to comply with the approved codes of practice, workers are not supposed to be working close to an operating machine.
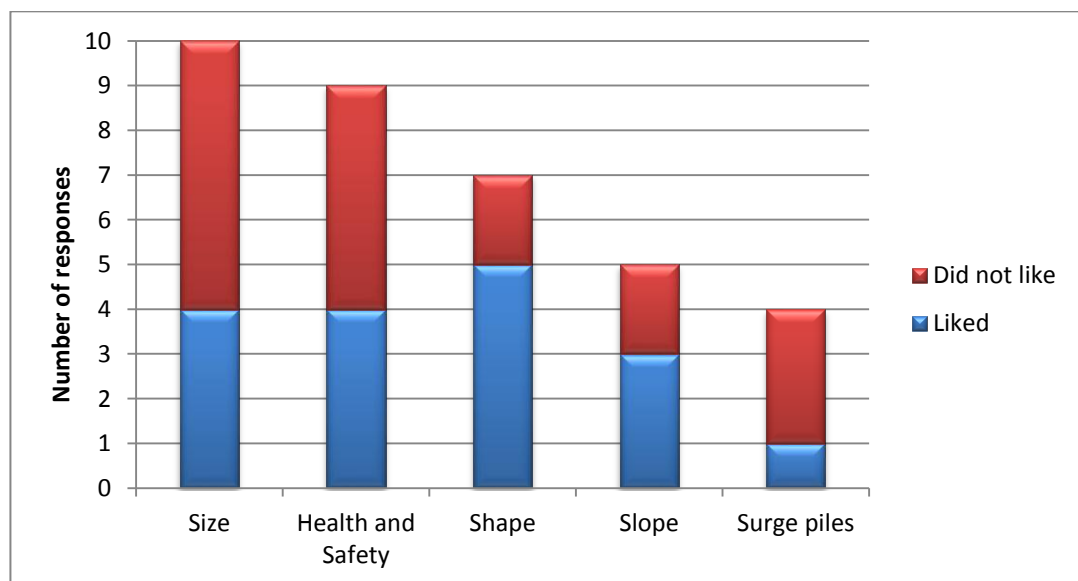

Figure 9 – Number of responses from contractors and whether they liked or did not like certain landing characteristics.

Seven contractors mentioned landing shape in their survey. Five of them like their elongated shape as it provided the most efficient fleeting and loading times and made good use of space. Two contractors described their landings as being too narrow, which increases the risk to worker safety particularly when trucks were being loaded.

Landing slope was not mentioned as much with only five of the contractors mentioning slope as an important characteristic. This may be because some did not think of it as they were on flat landings. Of the five contractors that mentioned slope, two did not like the slope their landings were on. The slope was not measured and was only minor but the two problems associated with slope were delimbing stems and loading trucks. When delimbing on a slope the heads often stabbed into the bank and broke off. Truck loading became dangerous on a slope particularly in the wet and with small diameter bark free logs as they had a tendency to slide off the truck when being loaded.

Three of the four contractors who mentioned room for surge piles as a valuable characteristic did not like the fact they had no room for surge piles. These were all small landings with steep sides where surge piles could not be placed on the cutover.

6. Discussion

This study has enabled some real time testing and analysis of landing size and its relationship to operational delays. Operational delays are strongly related to the productivity of harvesting crews as an increase in delays decreases their productive work time.

Initial results from the relationship between landing size and landing variables such as daily production align with that of several other studies (Hemphill, 1988; Raymond, 1987; Visser et al., 2010).

The relationship between processing delays per m^3 and relative landing size showed a reasonable trend, but was not statistically significant. The weakness of this model is most likely due to compounding errors originating from the regression equation that was developed based on 142 New Zealand landings to calculate the national average landing size. This equation was only designed to outline the major variables influencing landing size and was never developed for predicting delays. The relationship between processing delays per m^3 and actual landing size however, had a very strong linear relationship. This clearly indicates that in the sample tested, crews on smaller landings exhibit higher delays per unit of volume produced than those crews on large landings. The fact that this relationship is linear is somewhat of an interesting point; one would expect as landing size increased to a certain point it would no longer be inhibiting the operation and delays would not get much lower. This may be the case if a larger sample was used that covered a wider range of landing sizes.

The significance of this relationship can help forest owners and managers realise the implications of building landings that are too small for their intended purpose. The result of this increase in operational delays will not only affect the contractor but has the potential to financially affect harvest costs. To place it in a financial perspective, for example, a 150 tonne per day harvest operation working a nine hour day has an increase of processing delays by one minute per tonne due to their small landing. That is an extra 150 minutes of delays. There is potential for the crew to produce another 41.7 tonne without this delay. A typical logging rate paid to a harvest contractor is \$30/t, of which \$7/t would be a typical processing rate. The extra 41.7 tonne per day equates to a sum of \$292 per day in extra revenue for the contractor. If a contractor has to be paid even a

small proportion of this, say an extra $1.50/t because of his lower production levels on a smaller landing, this is an added harvest expense of $225 a day. Considering the length of time often spent by harvest crews at one landing this shows how spending an extra $2000-$4000 on landing construction could save a considerable amount on harvest costs in the long run.

Landing layout may have a significant effect on processing delays but is difficult to test and not included in this study. Crew 'J' had the smallest processing delays per m^3 and were on the largest landing. They were the only crew that had enough room to run two hot decks which they believed was the most efficient layout for processing. This shows that landing layout also has influence on delays but this was only achievable because they had a big enough landing to do so.

Loading deck delays were the most significant of any of the processing delays. This can be put down to delimbing and the availability of room for surge piles. The crews on small landings with no room for surge piles in the cut-over had to delimb each stem as it was placed on the deck to be processed. This greatly increased the loading deck delays and reduced processing time. Crews with large enough landings or landings on the flat where cut-over could be utilized for surge piles were able to have the loader delimb stems into separate surge piles during downtime such as when the skid workers were processing. This highlights the need for room to accommodate surge piles. If there are significant space or budget restrictions when building landings it could be possible to design the landing shape or layout in a way where there is provision for adequate surge piles. This should in turn decrease the overall processing delays.

The results of the conducted survey of what contractors value about their landings helps put what the contractors think in perspective. They are very aware of the implications that small landings have on their operations and this is why landing size is their most valued landing characteristic. They value landing size for two reasons, productivity and health and safety. All logging contractors want to maintain a safe working environment for their crew, and they are also required to do this by law. They believe that their crew are placed at higher risk when landings are too small, and are often forced to take unproductive actions to reduce this risk. Landing shape was the next most valued landing characteristic with all contractors preferring a rectangle shape at around 2:1.

The logging crews that were unable to have surge piles were very aware that this affected their production and this is also supported by the results of this study.

Forest harvesting operations, in terms of equipment and procedures, are highly variable, with no two operations exactly the same. This makes conducting studies difficult and there are often a number of limitations. The biggest limitation in this case is the size of the sample tested. Only ten harvest crews were included in this study. For more conclusive results a sample size of 25 to 30 would be best. Evidence suggests that small sample sizes can make it more difficult to get reputable data when using delays in a study as there are many variables that can influence delays particularly when human operated machinery is involved (Bergstrand, 1987). There is also a possibility that some bias has been introduced into the results as a result of the Hawthorne Effect. The Hawthorne Effect is a form of reactivity where subjects (in this case the harvest crew) modify their behaviour such as work speed in response to the fact that they know they are being studied.

The harvest operations used in this study were not working in large corporate forests but rather smaller woodlots and privately owned forests. This does not reduce the reliability of the data, but restricts it in the range of situations it can be applied. Woodlots generally tend to have smaller landings due to the volume of wood being put through them. Seven of the ten landings used in the study were all from the lower North Island, an area that is often restricted in the size of landings that can be built. Due to this the production of the crews is lower in general to other parts of the country.

This study has indicated some significant trends and has opened the door for more definitive studies to be carried out. This study only focussed on motor manual harvest operations and mechanised harvesting is a considerable proportion of New Zealand's harvest volume. There is the potential for similar studies to look at mechanised harvesting. In this case long term time studies would be viable with the use of on-board computer data loggers linked to the log processing computer. These future studies could also include other variables such as the environmental impacts of large landings or a cost benefit analysis of landing size and construction costs.

7. Conclusions

Landings are an important piece of infrastructure for New Zealand forest harvest operations. They are typically expensive to construct and their size is recognised as an important variable in maintaining a productive and safe operation.

This study showed that there is a strong trend between landing size and processing delays in that increasing landing size reduces processing delay time. Seventy-two percent of the variation in processing delays per m^3 was explained by landing size. This indicates that landing size is not the only variable affecting processing delays, but it does play a very significant role. The significance of this trend allows forest owners to see the implications of constructing landings that are too small for their intended purpose, in both decreased productivity and potentially increased harvest costs.

The most significant processing delay is that caused by large loading deck delays. These are a direct result of not having enough room for surge piles. Even if landings cannot be made any larger, ensuring there is enough room for surge piles should decrease processing delays.

Harvest contractors are very aware of how small landings negatively affect their operations; the relationships developed in this study support their ideas.

This study shows some good relationships, and has increased the understanding of landing size in relation to harvest productivity. Due to the small sample size tested and other limitations the study is best treated as a pilot study. It has opened the door for a larger study to be undertaken to gain more reputable results. It is possible that such a study could also take into account the environmental impacts of large landings and some kind of cost benefit analysis.

Acknowledgements

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Appendix 1

Verbal survey results of what the harvesting contractors liked and did not like about their landings

Logging Crew	What they liked about their landing	Did not like about their landing
A	Crew A likes that the road is two digger widths so that they can easy get next to the trucks rather than loading from behind. There are very few grades being cut due to the small size of the landing, making their log making easy.	They are only cutting short lengths as there is no room for long lengths in the stacks. The tight conditions make it dangerous. No room for surge piles so delimbing takes place as the deck is loaded. The delimber is on a slope which forces the heads into the ground and prolongs delimbing. The KIS end of the landing is on a slope making truck loading difficult. No room for waste which has to be removed in a bin truck.
B	Crew B likes the rectangular shape of their landing. When restricted to a small landing a rectangular shape makes more efficient use of space, particularly on their current setting.	There is no room for surge piles making loading of the deck very slow and stems are delimbed as they are loaded. Although the rectangular shape is good it is a bit narrow and some logs fall off the side posing a health and safety risk for breaker outs. The landing is on a slope making truck loading difficult, particularly in the wet. Overall the landing is too small.
C	The deck is central to the stacks, which makes for efficient fleeting. There is a good area for surge piles. The landing is flat and rectangular with a good solid surface. The landing is large and not confined at all which decreases the safety risk to workers.	At times two diggers are used on the landing, when loading trucks the operation stops as there is no room on the other side of the stacks for the loading digger to go. This results in the whole operation stopping when a truck is being loaded.
D	The landing is large compared to what this crew is used too. It has a good rectangular shape, is flat and has a metalled truck loading area. Because of the size of this landing this contractor believes the health and safety risk of the operation is lowered.	Very few problems with this landing. The only downside is extraction is uphill, however this is a landing location issue, not a landing size issue.
E	The contractor was away from this crew and the foreman had very little too say. He considered the landing average.	The size of the landing was too small, they are used to small landings but this one in particular needed more room for stacks. He believed this would have made his operation more efficient.

F	This contractor really liked the shape of his landing as it was rectangle. The soil was very sandy and free draining which was a benefit with recent heavy rain.	This landing had a farmer's fence right on the border of one side and a steep hill on the opposite. The fence could not be touched or removed. This landing was very small and only worked as the cutover could be used for surge piles. The small size was deemed to be a health and safety risk.
G	This contractor does not like anything about this landing.	The landing is very small making it quite dangerous. There is very little room for stacks which is resulting in only about half of the log sorts on the cut plan actually being cut. Delimbing takes place within the stump line as there is no room on the landing. To keep production up fleeting starts whist the logs are still being processed. The contractor is aware of the associated health and safety risks.
H	This contractor likes the large size of this landing and the fact that this provides ample room for surge piles and safe movement of men and machinery. The landing is on good soil, is flat and was constructed well before being used so the soil is settled and hard.	The landing shape is that of a triangle. The large size makes up for this but there is still some unused space because of the shape. There is a section of the landing that is too narrow and is very tight for the digger to move between the stacks and trucks at this point.
I	The landing is nice and flat, this is the only thing the contractor likes about this landing.	The landing is far too narrow; there is a fence in the way that has to be avoided. This crew usually runs two hot decks but there is not enough room on this landing to do so. This contractor believes that worker safety is compromised when only running one hot deck.
J	Fast and efficient processing using two hot decks. This keeps men away from the machines and makes the landing a safe working environment. Quick and easy fleeting of commonly produced log sorts from either deck. Using the two hot decks means the operation doesn't have to stop when loading a truck. They use vertical poles between the stacks to avoid grade mixing. Square shape makes twin hot decks possible.	There is not a lot of room for stacks when using two hot decks like this. Approximately one load per grade can be kept in inventory so truck timing is crucial.