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FALCON FORESTRY CLAW

A PRODUCTIVITY AND ERGONOMIC STUDY OF A MOTORISED HYDRAULIC GRAPPLE CARRIAGE

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SUMMARY

Currently New Zealand timber harvest volumes are at 23.5 million m^3 per year. This volume is expected to increase significantly over the next decade, as many more areas of plantation forest become available for harvest. As much of this up and coming available forest is on steep, difficult terrain the problem facing the industry at present is finding a way to harvest this safely and economically without compromising productivity. Moutere Logging in Nelson have begun to combat this problem with the development of a new hydraulic motorised grapple carriage, labelled the Falcon Forestry Claw (FFC).

Using an elemental time study the total delay free cycle time and productivity regression functions for the FFC were established. It was found that the total delay free cycle time of the FFC is very dependent on whether the carriage is hauling pre bunched stems or being feed stems by an excavator. Hauling pre bunched stems decreased total cycle time by 0.55 seconds while hauling stems fed from an excavator decreased cycle time even further by 0.79 of a minute. Using chokers instead of the FFC was found to increase cycle time by 0.91 of a minute. Other factors that effected cycle time were haul distance and hauling stems from a gulley. The productivity of the FFC was also found to be dependent on a number of factors including; whether stems were being hauled for a gulley or from back face, as well as haul distance and piece size. Using chokers instead of the FFC was found to increase productivity by 9.1t/PMH. Pre-bunching stems increases the productivity by 30.6t/PMH and when an excavator was used to feed stems to the FFC productivity increased by 43.6t/PMH.

Results from placing a heart rate monitor on hauler operators daily showed positive heart rate trends beginning to emerge, where the mental workload from operating the FFC was thought to be adequate. However, due to a limited amount of data the ergonomic performance of the FFC needs to continue to be considered.

All study sites consisted of 'easy' straight slopes which meant results are not completely applicable to hauling stems on adverse terrain. The varying time spent at each site limited true comparisons of the FFC, chokers and the FFC when working with pre-bunched stems and stems being fed by an excavator on a single standard site, resulting in a slight underestimation of the performance of the FFC. Overall the conducted study allowed for an adequate comparison of the FFC to chokers as well as the performance of the FFC when working with pre bunched stems and stems being fed by an excavator.

The FFC may not be the sole answer to solving the problem of harvesting the up and coming 'wall of wood', however, it is certainly a step in the right direction and an exciting new development. It shows potential in the New Zealand Forest Industry, with many benefits in terms of safety and lowering the crew numbers required to run a cable logging operations. Productivity benefits are also seen when using the FFC in conjunction with pre-bunching and feeding.

CONTENTS

Key Words: Steep terrain cable harvesting, cable logging, grapple carriage, motorized carriage, Madill 171, live skyline, operator stress, operator fatigue, heart rate strain.

1. Introduction

Currently New Zealand timber harvest volumes are at 23.5 million m^3 per year. This volume is expected to increase significantly over the next decade, as many more areas of plantation forest become available for harvest. It is estimated that 56% of the countries plantation forest estate is in first rotation. Of this first rotation forest 64% is aged 16 and above and will be available for harvest in the next 10 years, that is approximately 500,000 hectares [1].The majority of this forest is on difficult, *steep terrain*[A] of which, if economically viable, will be harvested using cable logging.

In New Zealand cable logging relies heavily on non carriage rigging configurations [2]. The majority of these operations use chokers which require breaker out personal on the hill side to manually hook-up stems for extraction. With such a job, where people are required to work on steep slopes, amongst logs and below large/heavy cables it comes as no surprise that many injuries and fatalities occur. Even with the current implementation of extensive safety procedures breaker out personal still make up 14% of all fatalities in forestry, only second to felling, as well as many of the serious harm (non fatal) injuries [3].It is clear the necessity for people to work on the hill side breaking out needs to be eliminated.

The problem facing the industry at present is finding a way to harvest this steep terrain[A] forest, not only safely but also economically without compromising productivity.

Moutere Logging in Nelson have begun to combat this problem with the development of a new hydraulic motorised grapple carriage, labelled the Falcon Forestry Claw (FFC). The FFC uses an internal combustion engine to power the hydraulic grapple and rotator. The FFC eliminates the need for choker setter personnel and also a spotter by incorporating a grapple which uses an inbuilt camera mounted on the underside of the carriage, allowing the operator to use an LCD screen with live real time feed in the cab to control the grapple and locate stems.

The vision is to have an ergonomically friendly and economically viable product that will increase productivity while eliminating the need for people on the hill side. The question remains is the Falcon Forestry Claw the answer?

This research report comprises of a critical review of relevant literature followed by a methodology detailing the study details, a section analysing the results from the study and lastly a critical review of the key findings.

**A – Steep slope defined as any slope unsafe to harvest using ground based machinery*

2. Literature Review

The steep terrain and fragile soils of New Zealand and our environmental constraints demand harvesting by cable haulers [4].

A recent survey of current cable logging operations in New Zealand showed that very few cable logging crews use carriage rigging configurations [2]. Only 4% of the cable operations surveyed used a motorised carriage as a preference, and only 28% have used one at any stage in the last five years [2]. It has often been reported that motorised carriages improve productivity [5-6], however there are surprisingly few studies to support such claims.

A 1970's magazine article states radio-controlled carriages for skyline logging have been used for some time [7]. A while later came grapple yarding allowing logs to be hooked remotely without breaker out personnel. This article describes a company in the West Coast USA 'big timber' country being the first to combine these two systems, using the 'Snapper" grapple carriage. The 'Snapper' carriage is thought to be the first of its kind, operating with electro-powered hydraulics. It employs a slightly modified grapple hook that can be opened, closed and rotated by a tone controlled high band portable radio. The grapple is powered by two 12 volt, 220amp/hour batteries. The batteries power the grapple for nine hours before needing to be recharged. The carriage weighs 5000 pounds (approximately 2.5 tonne); with the grapple opening span reaching 80 inches (approximately 2 meters). In a particular operation the "Snapper" was recorded to be hauling logs cut into lengths from 17 to 35 feet (approximately 5-9 meters) at an average distance of 1000 feet (approximately 305 meters), where the average piece size was recorded to be 46 inches (approximately 117 centimetres). The crew owner describes the 'Snapper" to be performing about five percent below production figures for a conventional operation, averaging "just less than 200 pieces a day". This suggests the opening and closing time of the grapple may have been significantly slower than that of a conventional mechanical grapple, as it would be expected the in haul and outhaul speed would not change a great deal. However, benefits of the carriage included "five men doing the work of eight". This article confirms that the concept of hydraulic grapple carriages has been around for some time and outlines some rough production values for such a carriage. However, no further information of the 'Snapper' carriage in operational use was found.

Current research on international grapple carriage developments report that the most innovative grapple carriage identified was made by Eagle Skyline Carriages with its remote-controlled, camera assisted, hydraulic actuation of the grapple and 360˚ grapple rotation [8]. This carriage marketed under the name Eagle Mega Claw and like the Falcon Forestry Claw, has been designed to operate on a live skyline rigging system in an uphill logging situation [8]. With the Eagle Mega Claw carriage being of similar design to the Falcon Forestry Claw it appears to be a comparable market product. However, no operational studies of such carriages in use were found. The end result of this research report stated that such innovations may produce faster work cycle times, and consequently increase productivity of cable logging systems used in New Zealand [8]; but again no studies have been found to support such statements. Figure 1 and Figure 2 below show the Eagle Mega Claw and the FFC, respectively, in operational use.

Figure 1: Eagle Mega Claw Grapple

Figure 2: Falcon Forestry Claw Grapple

A New Zealand study uses a Delphi process using 5 experts regarded motorised carriages as having great versatility [9]. Advantages reported include: Good lift and control of the drag, as well as the ability to lateral yard and navigate around or over obstacles. High associated productivity and fuel saving when shot gunning also made motorised carriages attractive. However, many could not justify the high capital investment in such a carriage, and were not willing to take on extra maintenance, risk skyline damage due to clamping, or the risk of dropping the carriage. Problems similar to live skylines with the hazard of overloading and the need for secure anchors were also perceived disadvantages [9].

The five experts also reported on grapple yarding in New Zealand. With less than 25% of crews using grapples in the last 5 years [2], grapple yarding is not a big feature of the New Zealand logging scene. Despite this, grapples were said to be very productive having no hook on element and therefore usually shorter cycle times. They require no breaker outs and therefore are a lot safer to operate. They were also said to be relatively simple, easy to set up, and are good for short distances. A major disadvantage was that if the yarder operator doesn't have good vision of the logs a spotter was required to communicate effectively with the yarder operator. Other disadvantages stated included rope wear, increased number of line shifts due to the inability to lateral yard, and limitations to shorter haul distances and specific terrain (i.e. concave slopes) [9].

A study of a grapple with a specifically designed restraint to limit its ability to rotate feely using a swing yarder extracting bunched wood reported a significant reduction in average grapple time at shorter haul distances when a spotter was not required. When the operator was offered the choice of using the grapple restraint or not, he emphatically said he would use it because it made the grapple more controllable. The contractor also stated that this ease of control also applied when a spotter was used [10].

The opportunity to motorise a grapple carriage can achieve a number of advantages, effectively combining positive elements of both the motorised and mechanical grapple carriages. They can be run on a two drum yarder (shotgun) or three drum (if haulback is required). They are controlled more directly, and are able to bring a more direct positive force to hold the payload. Additional control can also be used to increase payload through picking up multiple stems. Through the use of a rotor, the grapple can be turned to facilitate easy pick-up. Cameras mounted in, and powered by, the carriage also provide an opportunity to improve productivity and reduce the dependence on clear line of sight and or a spotter.

One method to analyse the productivity of the FFC is a detailed (elemental) times study. Literature reports that a detailed time study does an excellent job of comparing the delay-free production between alternatives [11]. Data collected from detailed time studies is often of high precision (within 1 second). Frequent small delays (<10 min) are also documented well. With a detailed time study, a large percentage of the variation (usually 50% or more) can be explained with a regression equation. 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 (random, unmeasured, or uncontrolled). This unexplained variation is also reported as the standard error of the dependent variable in most statistical programs, and it can be used in calculating the appropriate study length. There are some limitations associated with time studies. Because of their limited duration, this type of study is of limited value in accurately estimating long-term trends. Other major drawbacks of detailed time studies, in addition to the cost, are associated with the limited sample size. Large delays, which occur on average only once per day, are not adequately sampled [11]. The range of logging conditions is also limited when the study is done for only a few days. In this particular case, to determine the productivity of the FFC, a detailed time study is considered sufficient. It is also very important to recognise that there is no future in further developing the FFC if operator ergonomics are to suffer.

One study states that the use of cameras to assist a yarder operator in hooking on or grappling a load can be regarded as a kind of control system. The study of a fixed, cutover based video camera (radio link to operator TV display) found that in a steep canyon environment, a grapple yarder's production rate was nearly doubled [8]. There was no information indicating continued use of this technology.

Most recently a study on the fatigue and stress resulting from using the digital control system associated with the Falcon Forestry Claw 'prototype 3' carriage was conducted. The study reports the operator's brain as being over worked and unable to keep up with the mental demands placed on it [12]. This is confirmed by the heart rate and heart rate variability data which suggests the operator is stressed from operating the carriage and consequently becoming fatigued. The effect of this is a reduction in the operators overall performance. However, a number of limitations have been found to exist within this study. Limitations include: A very short duration of study (approximately half a day), the crew/operators limited experience using the carriage and the study being conducted extracting wood from only one single setting and using the same operator. A more robust study is required in order to investigate such claims.

3. Objective

The goal of this study was to help Moutere Logging improve the design of the Falcon Forestry Claw, motorised hydraulic grapple carriage. This study establishes a common benchmark for the current performance of such a product, enabling the New Zealand Forest Industry to see the potential of motorised grapple carriages.

4. Methodology

4.1 Site Characteristics

The study observed the Falcon Forestry Claw uphill logging at four clearfell sites in Nelson, over a cumulative 10 day period. The sites studies are shown in the Figures below.

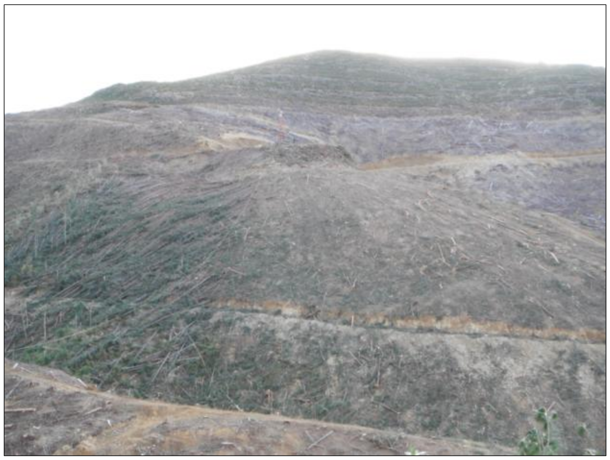

Figure 3: Site 1

Figure 4: Site 2

Figure 5: Site 3

Figure 6: Site 4

Table 1 outlines the key characteristics of each site. The time spent at each site can be seen to vary; this was mainly due to study time limitations and operational restraints. At Site 2 a Berger C19 *hauler*[B] was used, this however had been modified from a 50ft tower to a 70ft tower (like the Madill 171) and was therefore assumed to be comparable. All sites used a live skyline, slackline system, with sites 1 and 2 incorporating a ducthman line for lateral yarding capabilities. All tailholds were mobile (bulldozers), except site 2 which used a deadman.

***B - Note hauler/hauling = yarder/yarding for the entire report*

TABLE 1: KEY SITE CHARACTERISTICS

Site	Time collecting data (hr)	Avg Slope	Avg Piece Size	Avg Haul Dist	Hauler	Bunch/Feed	Chokers
1	35.2	55%	1.3	251m	Madill 171	No	Yes
2	10.40	45%	2.1	321m	Berger C19	No	No
3	6.93	30%	1.6	132m	Madill 171	Yes	Yes
4	14	35%	1.6	211m	Madill 171	Yes	No

Overall this study is considered to be a sufficient representative of the FFC working under standard operational conditions, allowing the productivity of the FFC to be adequately compared to the productivity when using chokers, or implementing feeding or bunching.

4.2 Productivity Study

An elemental time study was used to establish productivity functions for the Falcon Forestry Claw. The study split the yarder work time into four separate elements, as shown below. The time of each element was recorded using an inbuilt stop watch on a Garmin hand held GPS.

Work time elements for one cycle include:

1. **COUT** – Carriage out: Timed from when the carriage passes over a designated spot* on the end of the landing until it stopped above the stems to be hauled.
2. **GRAP** – Lowering the grapple and clamping the wood: timed from as soon as the carriage stops above the stems being hauled until the carriage starts to move, being in-hauled.
3. **CIN** – Carriage in: Timed from as soon as the carriage starts to move being in-hauled with a load of stems, until it passes the designated spot on the end of landing.
4. **UNHO** – Unhook: Timed from as soon as the carriage passes the designated spot on the end of the landing until the logs are lowered and unhooked and the carriage is back out to the designated spot on the end of the landing.

All delays were timed and categorised, as shown below.

- **OPDE** – Operational delay: Any activity that is necessary for operating the yarder but is not part of the primary function.
- **MEDE** – Mechanical delay: Any rigging or machine breakdown.
- **Del** – Any other delay

A number of factors were noted in order to link terrain parameters together and build appropriate productivity functions. The factors recorded are shown below:

- **BUT** – number of butt logs on pulled to the landing
- **TOP** – number of tops on pulled to the landing
- **Distance** – distance along the corridor, measured using a range finder.

Block factors were recorded in order to determine the variation between feeding the grapple, grappling bunched stems and grappling unbunched, felled stems. The variation in extracting timber from a front face slope, gully or back face slope was also recorded. These block factors were not measured in the way that quantitative variables are; rather, they were coded with 1 or 0 to indicate yes/no of a particular condition. For example, a block factor was used to document whether preset chokers were in place during a given cycle: 0 = not preset; 1 = preset. This block factor then permitted comparison of each alternative against the FFC performance. The block factors recorded are as follows:

- **NBUN** – No bunching/feeding the grapple stems.
- **Bunch** – F (fed by excavator), B (pre-bunched on hillside), N (none, i.e. simply picking up felled trees).
- **FACE** – F (front face), B (back face), G (Gulley)

Stepwise linear regression analysis enabled separate cycle time and productivity equations to be developed. This analysis was completed using the IBM SPSS statistics computer program. The statistical significance of the alternatives was automatically reported by the p-value for each block factor. If an block factor was significant ($p<0.05\%$), its coefficient represents a statistically significant difference for that alternative and the total delay free cycle time or productivity for the FFC [11]. Any insignificant variables were automatically discarded.

The profile of the hill side at each setting was measured using a clinometer and a range finder, including the slope and distances of the front face and back face, enabling a detailed description of the study areas, as seen in Table 1.

The diameter of stems and tops on the landing, at 2m intervals using calipers and a 30m measuring tape, were recorded daily during lunch breaks. The aim was to measure at least 15 trees daily in order to gain a clear representation of the piece size of the stems being hauled. However, due to time restraints at some operations this was not achievable at all sites. Where this was not achievable the Waratah daily production was used, where the average piece size was estimated from the total daily number of stems recorded during the time study and divided by the daily production. Tops were assumed to be 20 percent by mass of the total piece size.

4.3 Ergonomic Study

At the start of each day the Polar RS800 heart-rate monitor was placed on the yarder operator. The operators' heart beat was recorded relative to the delays. If the absolute value of the difference in time from one beat to the next is larger than 100ms the data point is considered to be an artifact and was removed. The relevant beat per minute heart rate data was then analysed for overall trends relating to the operators mental and physical state. Visual comparison of these results to the delays enabled hypotheses to be formed as to areas of the operators' job which are causing stress or fatigue.

5. Results

5.1 Statistical Analysis

5.1.1 Cycle Time Analysis

A regression model calculating the total delay free cycle time is shown below in Equation 1.

$$\boldsymbol{Total\ Cycle\ Time\ (min)\ =\ 2.36\ +\ 0.41G\ +\ 0.007D\ +\ 0.91C - 0.552B - 0.79F}$$

Equation 1: Total cycle time regression analysis

- ***R^2 = 0.42***

Where,

- D = haul distance (m)
- G = hauling wood from a gulley
- C = using chokers and not grapple
- B = grappling bunched stems
- F = grappling stems fed by excavator

It was found that the total delay free cycle time of the FFC is very dependent on the block factors; that is whether the carriage is hauling pre bunched stems or being feed stems by an excavator. If bunching was to be used the cycle time of the FFC decreased significantly, by 0.55 of a minute. The cycle time of the FFC was found to be most affected when being fed stems from an excavator, decreasing by 0.79 of a minute. Using chokers was shown to increase cycle time by 0.91 of a minute. This is mainly due to the difference in accumulation time, where having to hook-up logs using chokers took more time than grappling logs with the FFC. Hauling wood from a gulley was also seen to increase the cycle time of the carriage, as was further increasing the distance of haul.

Figure 6 shows the correlation of the regression estimated total delay free cycle times and the actual measured cycle times. It can be seen that the regression eliminates any outliers and tends to correlate well with the actual measured cycle times. This figure also illustrates the effect shown by the distance coefficient in the regression equation where it can be seen that as haul distance increases so does the cycle time. Although, the distance parameter appeared to have a slightly lesser effect on the total cycle time compared to the block factors. This was due to the out haul and inhaul times increasing at almost a constant linear rate with distance. The time to accumulate the stems was found to be the element of total cycle time mostly affected by the system being used to haul stems (e.g. chokers or FFC or FFC with bunching or feeding).

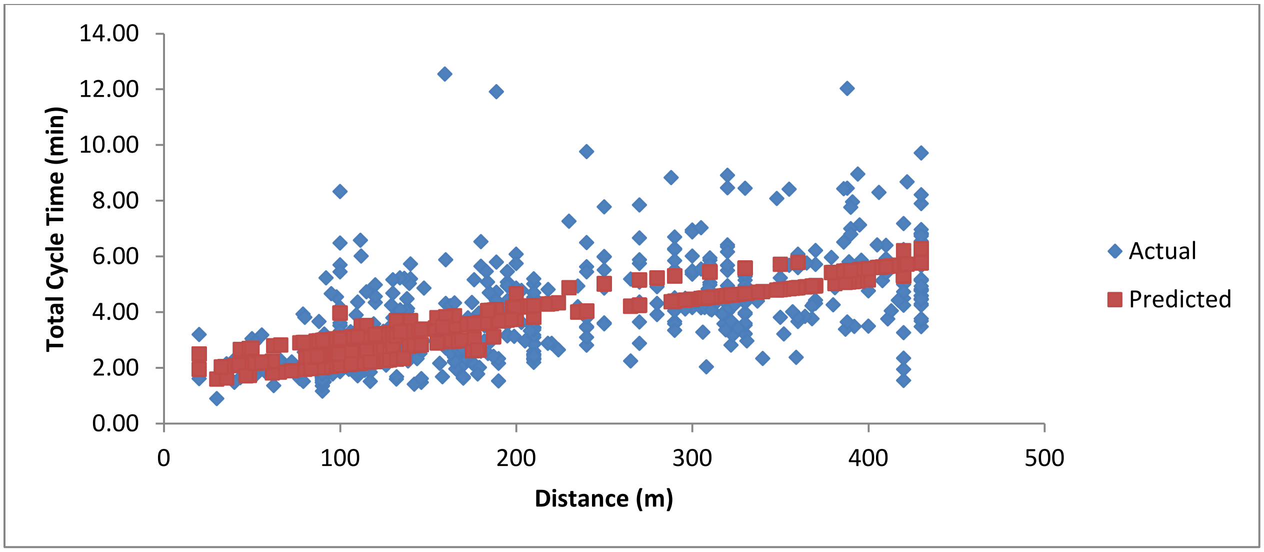

FIGURE 6: GRAPH SHOWING THE COMPARISON OF THE OBSERVED TOTAL CYCLE TIME AND THE PREDICTED TOTAL CYCLE TIME FOR THE REGRESSION ANALYSIS.

Regression analysis did show Sites 3 and 4 to also be significant. This indicates that some other parameters affecting the model were not accounted for. As Sites 3 and 4 had the same crew this was likely to be due to different terrain conditions affecting performance.

Table 2 displays a summary of the mean total delay free cycle time results for the FFC when being used standard, with pre-bunching and with being fed by an excavator. The total delay free cycle time of chokers is also shown. The cycle time of the FFC is seen to be lower than that when using chokers. This is attributed to a shorter accumulation time, as previously mentioned. The FFC working with bunched stems significantly decreases cycle time. The FFC working with stems being fed from an excavator the cycle time is seen to decrease even further. The range of cycle times shown is likely to be affected by the range of distances. Using the FFC (without pre-bunching or feeding) and also chokers have been tested on a significantly larger range of haul distance.

TABLE 2: SUMMARY OF TOTAL DELAY FREE CYCLE TIMES FOR RESPECTIVE SYSTEMS

	Mean cycle time (min)	**Min cycle time (min)**	**Max cycle time (min)**	**Range (min)**	**Min Dist (m)**	**Max Dist (m)**	**Range (m)**
FFC	4.22	2.5	5.78	3.28	20	430	410
Chokers	5.27	3.97	6.28	2.31	100	430	330
FFC with Bunching	2.64	1.95	2.64	0.69	20	187	167
FFC with Feeding	2.12	1.6	3.14	1.54	30	179	149

5.1.2 Productivity Analysis

A separate regression model was produced for calculating the total productivity of the FFC, as shown in Equation 2.

$$\boldsymbol{Productivity\ (t/PMH) = 29.9 - 0.054D + 9.4PS - 6.7G - 13.2R + 9.1C + 30.6B + 43.6F}$$

Equation 2: Productivity regression analysis

- ***R^2 = 0.45***

Where,

- D = haul distance (m)
- PS = piece size (t)
- G = hauling wood from a gulley
- R = hauling wood from back face
- C = using chokers
- B = grappling bunched stems
- F = grappling stems fed by excavator

As shown in Equation 2 the total productivity of the FFC is dependent on a number of block factors. Hauling wood from a gulley is seen to decrease productivity by 6.7t/PMH. Hauling wood from back face decreases productivity even further by 13.7t/PMH. This extra decrease in productivity is thought to be due to the increase in the distance when hauling wood from a gulley and the even further increase in distance when hauling wood from a back face. Evidentially, a longer haul distance also decreases productivity in the regression model. This decrease in productivity is displayed by the trend in Figure 7. An increase in piece size increases productivity, as expected. The factors effecting productivity mentioned so far are mostly out of control of the logging crew, meaning that they are difficult to modify in day-to-day logging operations. However, using chokers or bunching or feeding the FFC with an excavator are all realistic interchangeable options. Using chokers is seen to increase productivity by 9.1t/PMH. Pre-bunching stems increases the productivity by 30.6t/PMH, more than three times as much when compared to using chokers. Using an excavator to feed the FFC increases the productivity by 43.6t/PMH, which is even more than when pre-bunching for the FFC.

Regression analysis did show Sites 2 and 4 to also be significant. This indicates that some other parameters affecting productivity were not accounted for by the regression model. These parameters are likely to include: crew experience, more specifically operator experience and hauler effect where Site 2 used a Berger C19 and Site 4 used a Madill 171.

The Figure 7 shows the correlation of the regression estimated productivity and the actual measured productivity. It can be seen that the regression eliminates any outliers and tends to correlate well with the actual productivity. This figure also illustrates the effect shown by the distance coefficient in the regression equation where it can be seen that as haul distance decreases productivity. Although, the distance parameter appeared to have a slightly lesser effect on the productivity compared to the block factors. This was due to the out haul and inhaul times increasing at almost a constant linear rate with distance. The time to accumulate the stems was found to be the element of total cycle time mostly affected by the system being used to haul stems (e.g. chokers or FFC or FFC with bunching or feeding).

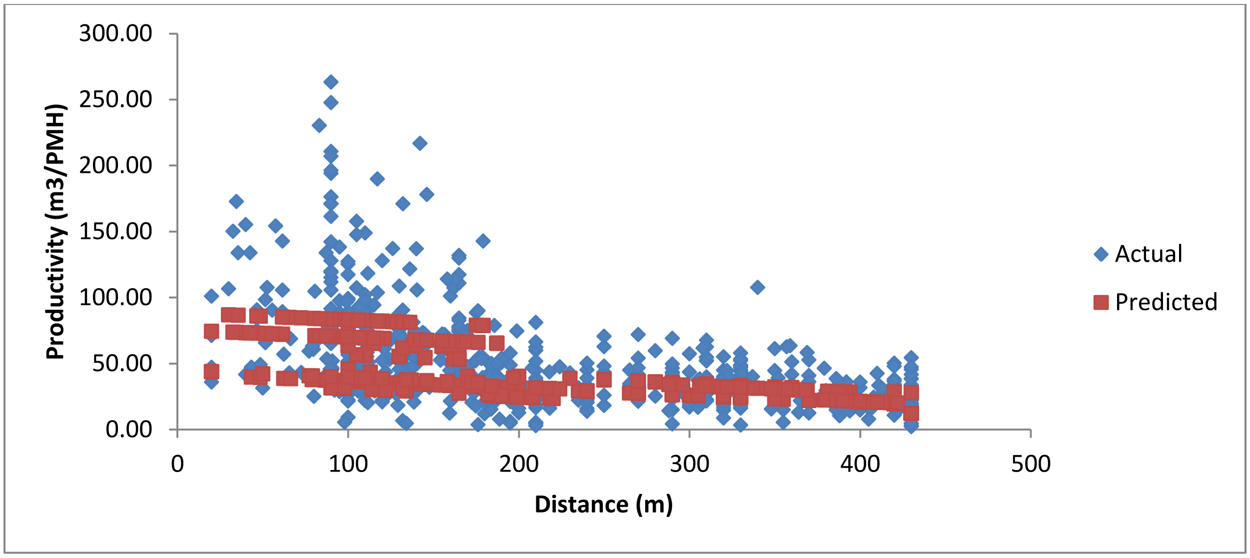

FIGURE 7: GRAPH SHOWING THE MEASURED PRODUCTIVITY AND THE PREDICTED PRODUCTIVITY OF THE FFC.

Figure 8 shows the change in productivity when hauling stems from different positions on the slope (i.e. front face, gulley and back face) relative to the system being used to haul stems. Productivity when hauling stems from a front face for all four systems is consistently higher than when hauling from a gulley or back face. When the FFC is being fed using an excavator the productivity decreases when hauling stems from a gulley and the productivity decreases even further when hauling stems from a back face. When using the FFC standard and when using the FFC with bunching and hauling wood from a back face the productivity is shown to be higher than when hauling stems from a gulley. This is not an expected result as the back face is a greater haul distance than a gulley. However, this is thought to be explained by differences in sites and crew/hauler operators.

When chokers were in use no stems were hauled from a gulley, hence no value for productivity. Ten cycles were recorded using chokers to haul stems from a back face, where bunching/feeding assisted the operation. These 10 cycles were removed as outliers for the purpose of this comparison as they were not regarded a large enough sample for statistical analysis. Nevertheless, it is interesting to note that for the 10 cycles when using chokers the mean productivity came out as 64t/PMH, almost double using chokers without feeding/bunching and significantly higher than when using the FFC with pre bunching on a back face.

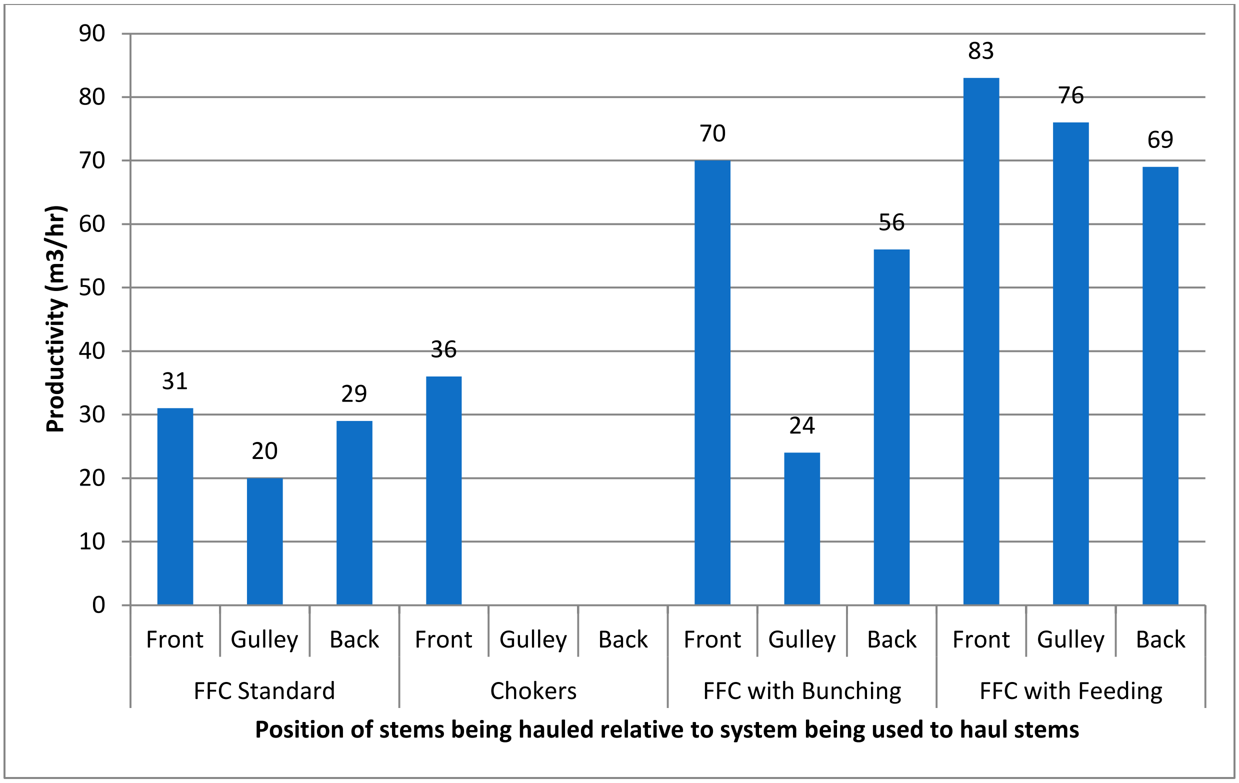

FIGURE 8: CHANGE IN PRODUCTIVITY WHEN HAULING STEMS FROM DIFFERENT POSITIONS ON THE SLOPE RELATIVE TO THE SYSTEM BEING USED TO HAUL STEMS.

Table 3 is an example that highlights the productivity of the FFC compared to different systems. It is clear the productivity is higher when using chokers; however there are significant safety benefits when using the FFC instead of chokers, where as many of three people (2 breaker out personnel and a poleman) may be removed from harm's way. The FFC working with pre-bunched wood increases productivity significantly and may be used without a machine on the slope, that is if mechanised felling is used where stems can be pre-bunched prior to extraction. Using an excavator to feed the FFC yields the highest productivity, however it does require a machine on the slope for the duration of extraction.

TABLE 3: FFC PRODUCTIVITY EXAMPLE; D = 210M; PS = 210M; HAULING FROM FRONT FACE

System	Prod (t/PMH)	Cost / Safety Consideration
Chokers	41.8	Standard
Falcon Claw	32.7	No choker-setter
Falcon Claw working with bunched wood	63.3	Mechanised felling / bunching
Falcon Claw being fed by excavator	76.3	Machine on slope for duration of extraction operation

5.2 Operational Analysis

Over the duration of the 68.04 hour study 600 FFC cycles were recorded. The total accumulated delay measured in this period was 30.21 hours. This resulted in 37.83 productive machine hours, giving the FFC an utilisation of 56%. Refer to Table 4 for a summary of results.

TABLE 4: SUMMARY OF FFC OPERATIONAL DATA

Study Duration (SMH)	68.04
Total Number of Cycles	598
Total Delays (hr)	30.21
PMH	37.83
Utilisation	56%

Figure 9 shows the overall delay time accounts for 44% of the operation. All delays, mechanical, operational and other were seen to evenly account for the total delays of the operation.

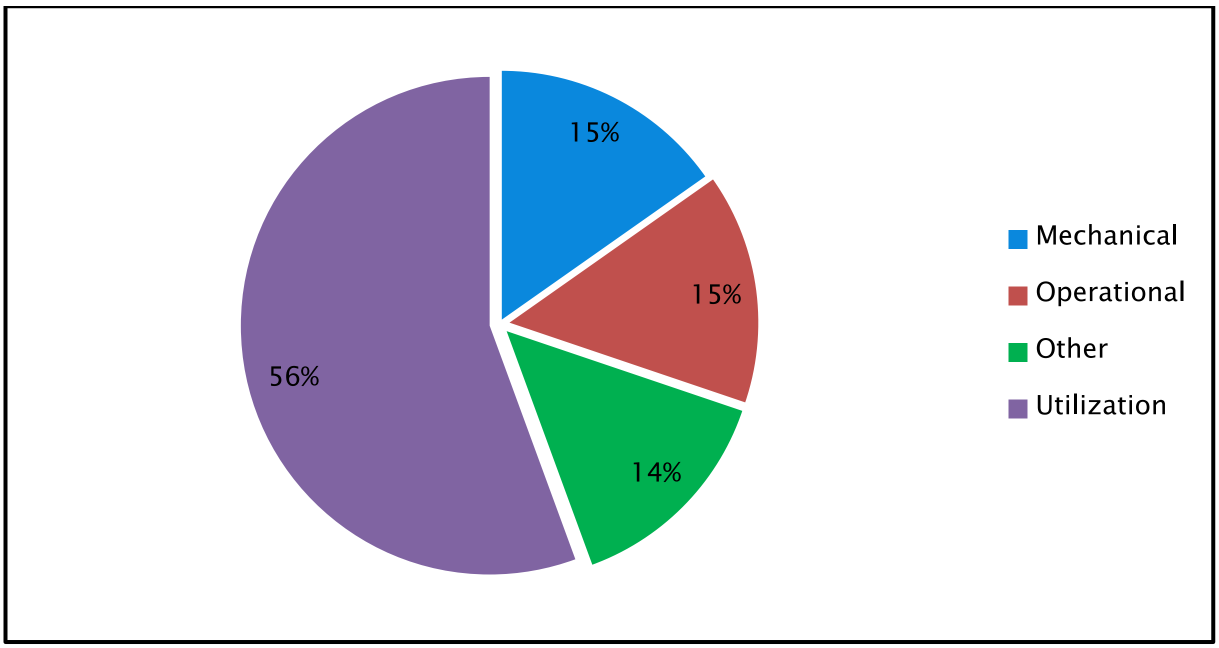

FIGURE 9: BREAK DOWN OF THE OPERATION

Figure 10 shows a breakdown of the delays. The largest delay, at 30% comes from the other delays section, mainly accounting for social delays such as required lunch breaks. The next significant delay was due to mechanical hauler delays, at 20%. This was a result of the hauler losing a track when being shifted resulting in a loss of half a day of productive work. Line shifts also accounted for 20% of total delays. The total FFC mechanical delays accounted for 15% of all delays. Much of this was due to the carriage hitting the side of the hill causing a hydraulic ram to shear off resulting in almost a half day loss of productive work. Rigging delays make up 9% of all delays. Much of this is due to time lost when switching from the carriage to chokers, as well as snapping a dutchman line. At Sites 3 and 4 where feeding and bunching was incorporated, some delays were noticed with the carriage waiting for the excavator to bunch logs as well as stems falling off the front of the skid forcing the FFC to waste time and re-grapple these logs.

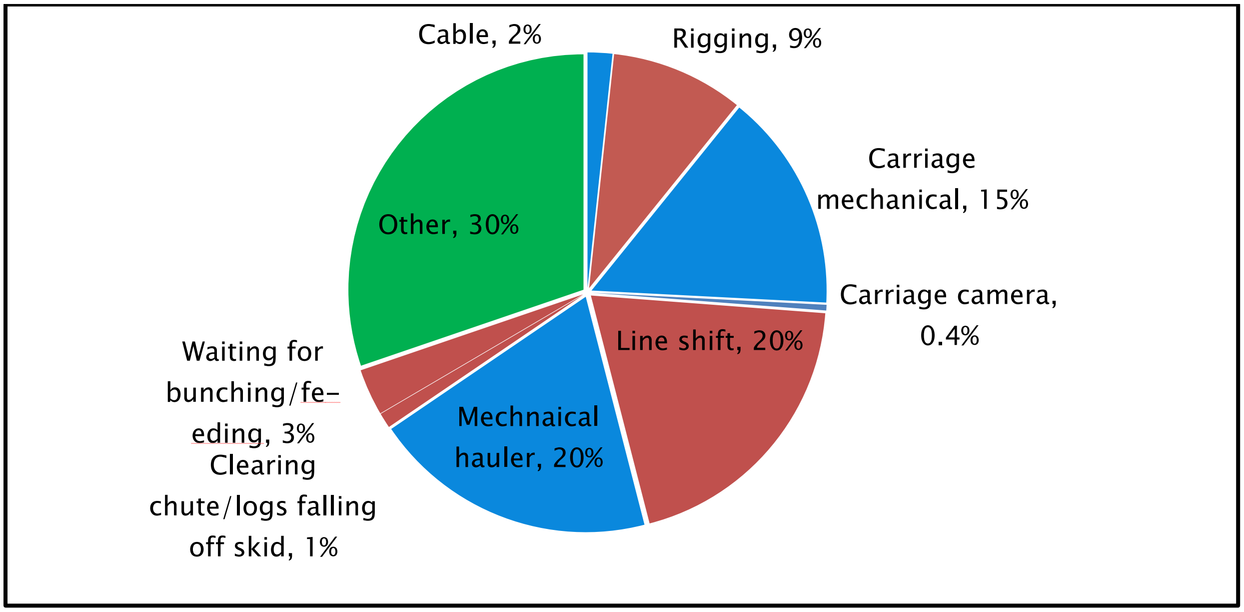

FIGURE 10: BREAKDOWN OF THE DELAY COMPONENTS OF THE OPERATION

5.3 Heart-Rate Analysis

Figure 11 displays the hauler operators beat per minute (BPM) heart rate for the duration of the day (approximately 9 hours) when using chokers. The operator's average heart rate is 97 BPM. Five areas (a-e) where the operators' heart rate increases significantly can be seen, refer to Appendix 1 for a description of increases in heart rate. The most extreme increase is where the heart rate almost reaches 160 BPM, at approximately two hours. This is attributed to the operator needing to exit the cab and having to physically unhook the FFC and assist in the application of chokers. Overall there is a decreasing trend in heart rate, when the operator is using chokers. This indicates the operator is settling in to his role throughout the day and hence is not become fatigued or stressed.

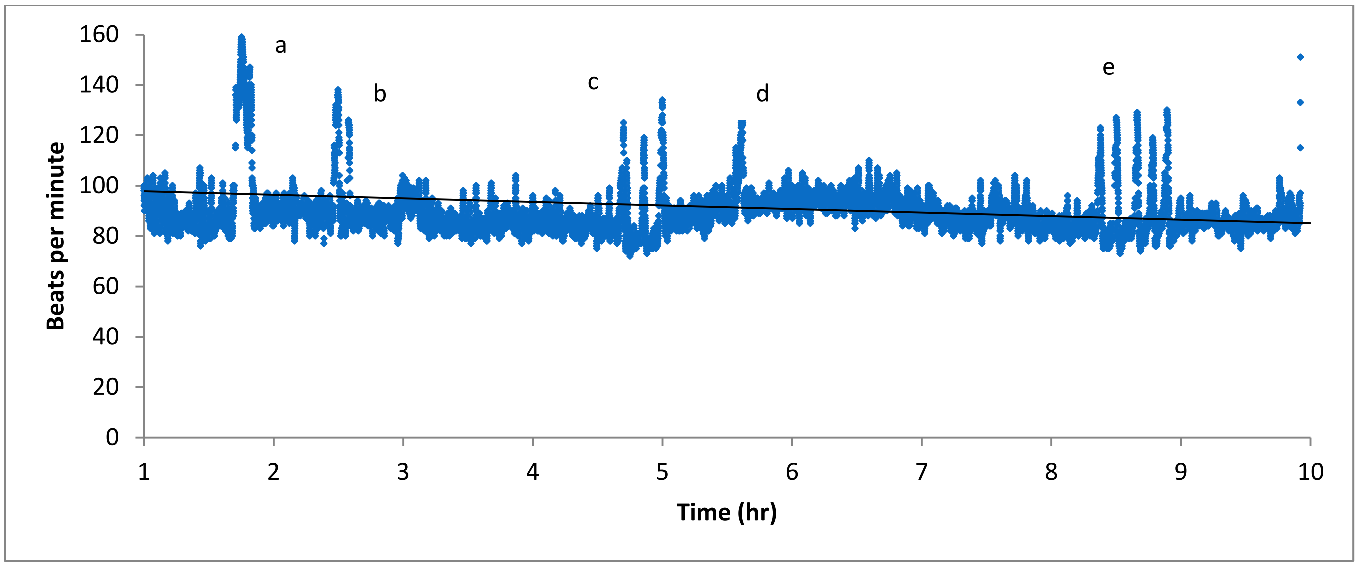

FIGURE 11: DAY FOUR, SITE 1, HAULER OPERATOR BEATS PER MINUTE VERSUS DURATION THROUGHOUT DAY WHEN USING CHOKERS

Figure 12 heart rate monitoring begun after lunch on this particular day, therefore there is only 4 hours of data. The operator's average heart rate is 79 BPM. Three areas where the operators' heart rate increases significantly can be seen refer to Appendix 1 for a description of increases in heart rate. The most extreme increase is at point b, where the heart rate almost reaches just above 120 BPM. This is attributed to a tailshift, where the operator required greater concentration as operating the hauler and communicating with the tailhold operator at the same time was required. Overall there is an increasing trend in heart rate, when the operator is using the FFC for this particular day. This indicates the operator is becoming slightly fatigued/mentally stressed as the day goes on.

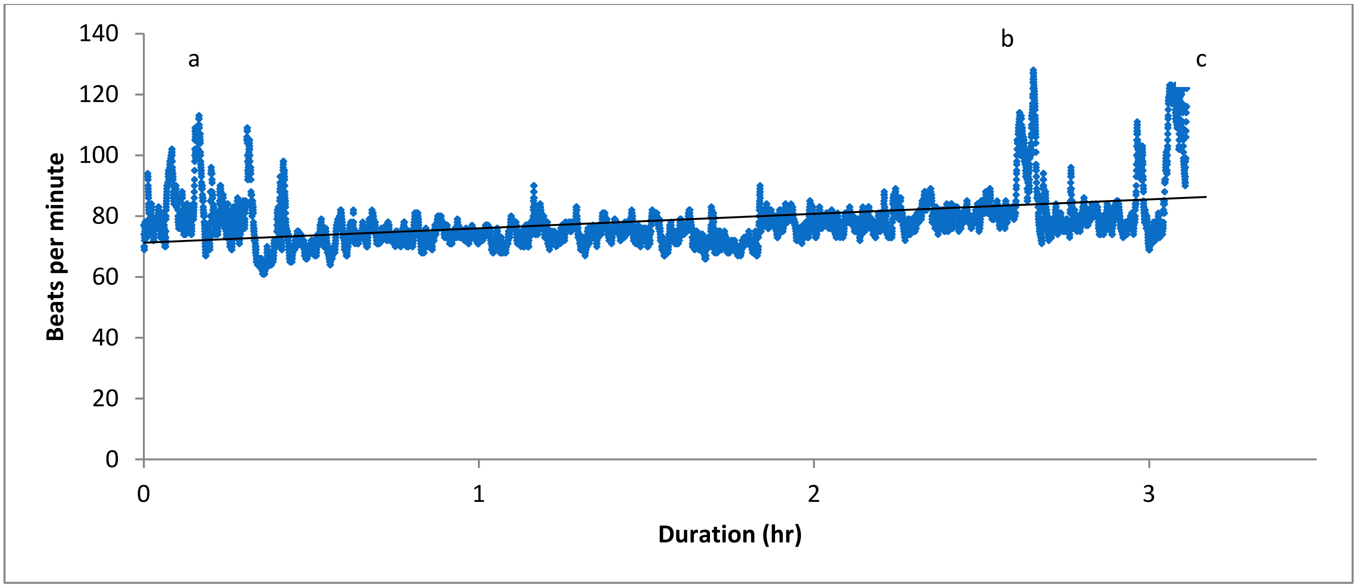

FIGURE 12: DAY SIX, SITE 2, HAULER OPERATOR BEATS PER MINUTE VERSUS DURATION THROUGHOUT DAY WHEN USING FFC

Figure 13 displays the hauler operators beat per minute (BPM) heart rate for the duration of the day (approximately 9 hours) when using the FFC on day seven. The operator's average heart rate is 80 BPM, which matches the average heart rate shown on Figure 12, being the same operator. Three areas where the operators' heart rate increases significantly can be seen, refer to Appendix 1 for a description of increases in heart rate. The most extreme increase is where the heart rate almost reaches 150 BPM, at approximately the 6 hour mark. This is attributed to mechanical problem with the FFC, where the operator was required to exit the cab and visually inspect the FFC. Overall there seems to be a reasonably flat trend in heart rate, when the operator is using the FFC for this particular day. This indicates the operator is comfortable using the FFC as is therefore not becoming fatigued or stressed.

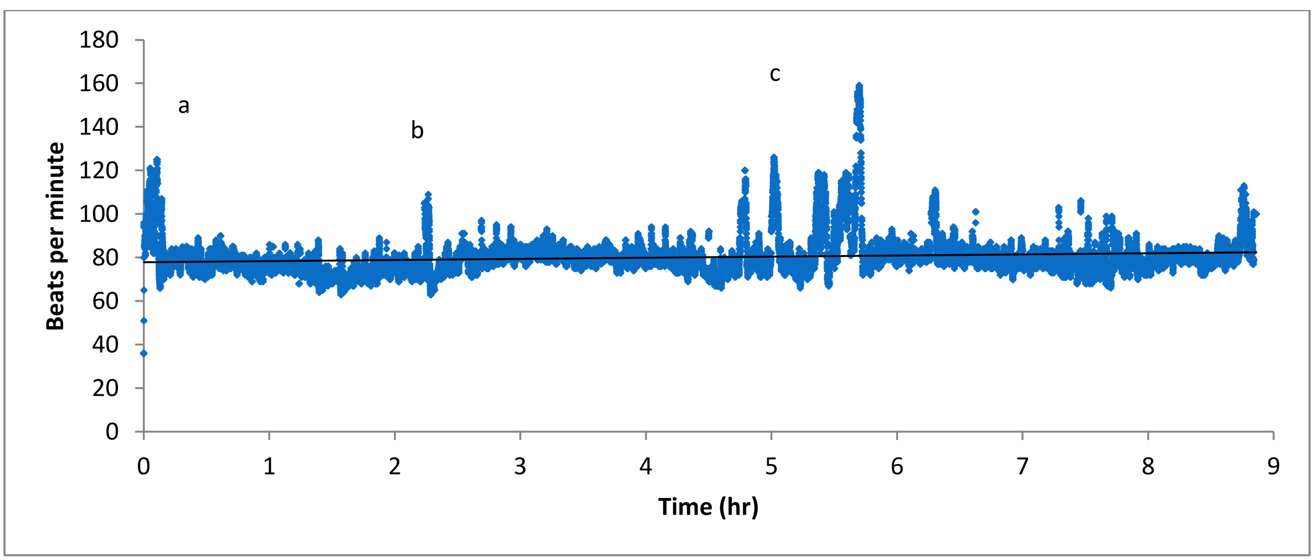

FIGURE 13: DAY SEVEN, SITE 2, HAULER OPERATOR BEATS PER MINUTE VERSUS DURATION THROUGHOUT DAY WHEN USING FFC

Figure 14 displays the hauler operators beat per minute (BPM) heart rate for four hours when using the FFC, with the aid of bunching/feeding, on day nine. Due to operational delays heart rate monitoring begun after lunch. The operator's average heart rate is 98 BPM. Four areas where the operators' heart rate increases significantly can be seen, refer to Appendix 1 for a description of increases in heart rate. All four cases can be attributed to the operator needing to wait for the chute to be cleared, as the Waratah could not process stems faster than they were being hauled. Overall there seems to be a reasonably flat trend in heart rate, when the operator is using the FFC with the aid of bunching/feeding for this particular day. This indicates the operator is comfortable using the FFC with the aid of bunching/feeding and therefore is not becoming fatigued or stressed.

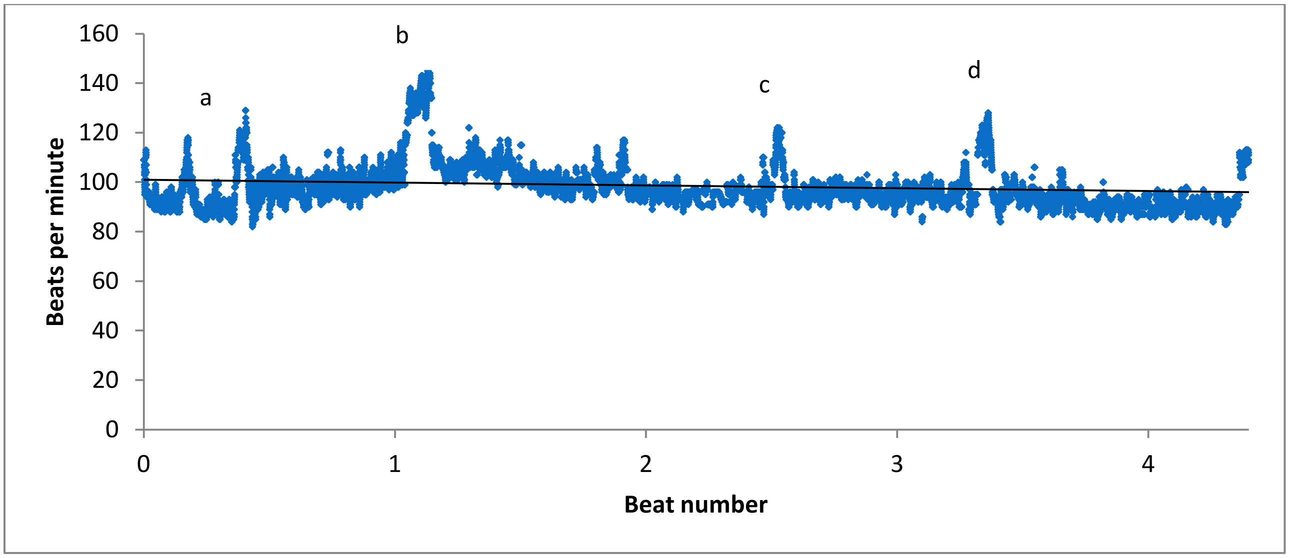

FIGURE 14: DAY NINE, SITE 4, HAULER OPERATOR BEATS PER MINUTE VERSUS DURATION THROUGHOUT DAY WHEN USING FFC WITH BUNCHING/FEEDING

6. Discussion

This study enabled the total delay free cycle time and the productivity of the FFC to be established. The performance of the FFC was able to be compared against using chokers as well as the performance when working with pre bunched stems and stems being fed by an excavator. From the data gathered and the limitations noted it was found that the FFC is less productive than chokers. Conversely, the FFC does offer significant safety benefits, in removing people off the hill side, of which that cannot be ignored. However, quantifying theses safety benefits and comparing them to the slight loss in productivity is difficult and requires further detailed analysis. Eliminating people off the slopes also presents the opportunity for cable operations to be run by smaller crews, which may become more favorable in the future considering the ageing forestry workforce and that fewer young people are choosing logging as a career.

The FFC working with bunched stems or stems being fed from an excavator was found to considerably increase productivity. However, due to the slope limitations of mechanised felling machines and excavators this is only possible on relatively gentle slopes. It should be noted that a true comparison, testing the FFC on the same slope as when using the FFC with pre-bunched stems and using the FFC when being fed stems was not possible due to operational constraints. This may have resulted in the productivity of the FFC being slightly under-estimated; where if it was to be used on the same terrain where bunching/feeding was used its productivity may have been higher.

This study has been conducted in the Nelson area and is therefore limited to straight slopes. It is not applicable to more adverse terrain that may incorporate such feature as bluffs.

In the cycle time regression model Sites 3 and 4 showed up as significant as did Sites 2 and 4 in the productivity model. These were most likely due to uncontrolled variation of which parameters in the models could not account for. Uncontrolled variation that may have caused such results could be due to the level of training and skill of the crews/hauler operators. Especially since the crews at Sites 1 and 2 had only been using the FFC for a couple of months where as the crew at Sites 3 and 4 have had ‘prototype 2’of which they had been using since early April, approximately half a year. Operator aptitude should also be considered where all of the operators were most likely in the early to mid range stages of the learn curve. As the FFC is a new product effective operator training may not have been initially possible, however it is suggested that operators who have used been exposed to the FFC for the longest period of time offer training to other operators who have not been using the FFC for very long [13]. Other sources of uncontrolled variation include: the difference in equipment (as discussed in section 4.1), crew motivation and team coordination.

The total utilisation of the operation was 56%. This was considered to be slightly biased by the track falling of the hauler causing almost three quarters of a day to be lost. This is not a common cause of delay and has a very low chance of occurring on a regular basis. This illustrates one drawback of elemental time studies where large infrequent delays cannot be adequately sampled. Ideally in a longer and more robust study a combination of shift level data and detailed time study data would be used. Shift-level data is usually collected over long periods of time (several months or more). Shift-level data provides a summary of the daily activity as recorded by one of the logging crew [11]. For this operation the hauler operator is in the best position to record the data. Shift-level data would be used to record large delays and time-related changes, such as long-term productivity improvements. The detailed time study data could then be used to show the difference in delay-free productivity under standardised conditions.

Using the operator heart rate data the ergonomic performance of the FFC is thought to be adequate. However, it should be noted that only a very small sample of heart rate data was measured. Ideally the full cardiovascular health history of each operator would be known along with operator age. The resting heart rate of each operator would also need to be measured to enable a more detailed comparison of data. The true ergonomic performance of the FFC should be continued to be investigated in a further more specific study.

7. Conclusions

This study establishes appropriate cycle time and productivity regression models for the FFC claw. These models allow for an accurate comparison between the FFC and chokers. The performance of the FFC when hauling pre-bunched stems and when hauling stems fed by an excavator was also able to be adequately determined. Moutere Logging and the New Zealand Forest Industry are now able to see the factors affecting the cycle time and productivity of the FFC. A more robust study eliminating some of the limitations mentioned throughout the report would provide more accurate results.

Some trends associated with the ergonomic performance of the FFC were emerging, however the ergonomic performance of the FFC will need to be continued to be considered.

The FFC may not be the sole answer to solving the problem of harvesting the up and coming ‘wall of wood’ on steep terrain, however, it is certainly a step in the right direction and an exciting new development. It shows potential in the New Zealand Forest Industry, with many benefits in terms of safety and lowering the crew numbers required to run a cable logging operation. Productivity benefits are also seen when using the FFC in conjunction with pre-bunching and feeding.

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Appendix

Appendix 1

TABLE 3: DESCRIPTION OF HEART RATE INCREASES FOR EACH HAULER OPERATOR

Point	Study Day			
	4	**6**	**7**	**9**
a	Out of cab - removing grapple and hooking on chokers	Tried to grapple root ball stem but to heavy kept slipping out of grapple	Out of cab - Beginning of day	Waiting for chute to be cleared
b	Trouble landing stems	Tailshift	Trying to knock over tree with grapple	Waiting for chute to be cleared
c	Out of cab - lunch time	End of day	lunch/carriage mechanical problems	Waiting for chute to be cleared
d	Tailshift	-	-	Waiting for chute to be cleared
e	Tailshift	-	-	-