Productivity Potential of the Harvestline Cable Yarder: Results of three Case Studies

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Executive Summary

Cable yarders are used to carry out timber extraction on steep terrain all over the world. In New Zealand we have traditionally used the larger sized North American yarder design which are powerful and able to extract large trees, but also expensive to operate. Smaller excavator-based yarders may provide a good alternative in stands with smaller trees, but also for woodlots. Their smaller size provides ease of setting up and also the ability to carry out rapid line shifts.

The Harvestline is one such excavator-based yarding machine manufactured by EMS in Rotorua. They have built around 60 machines that are working worldwide. A time study obtained productivity data for three Harvestline operations. A GPS was attached to the Hawkeye grapple carriage to analyse its movements over the workday. I also spoke with operators, contractors and personnel at EMS Rotorua to get their impression of the machine. This information was then analysed to better understand the capabilities of the Harvestline.

In total 8 days were spent in the field, recording 1030 cycles, including 353 cycles in Mosgiel, 431 cycles at a Rotorua based operations, and finally 246 cycles in Opotiki. In Mosgiel the average slope was 30 degrees, average extraction distance 105 meters, and average piece size was 2.0 tonnes. The resulting average cycle time was 1.37 minutes, productivity 86 t/PMH, with a utilisation rate of 57%. The average velocity of the carriage on the outhaul was 4.0 m/s and the inhaul was 3.8 m/s. In Rotorua the average slope was also 30 degrees, average extraction distance 96 meters and piece size was 1.9 tonnes. This resulted in an average cycle time of 1.4 minutes, a productivity of 77 t/PMH, and a utilisation rate of 50%. The average velocity of the carriage outhaul was 3.8 m/s and the inhaul was 3.0 m/s. Finally, in Opotiki average slope was steeper at 35 degrees, average extraction distance longer at 181 meters, average piece size larger at 2.3 tonnes. This resulted in an average cycle time of 2.45 minutes and a productivity of 58 t/PMH, with utilisation at 64%. Velocity of the carriage outhaul was 4.0 m/s and the carriage inhaul was 2.8 m/s.

This data shows that the Harvestline, working at a variety of distances, piece sizes and terrain, is a very capable machine. Analyses and general observations during the field study showed that the Harvestline was very productive out to about 250 m, and then the productivity started to drop, but that is similar to other yarder options. The absence of guylines meant that other machines could work closer to the yarder, making it ideal for smaller landings. The Harvestline also did very well in manually felled areas (where butt ends of the stems are not presented nicely) due to being able to move around or swing left/right to grab the best part of the stem. All three operators liked the reliability, cabin layout of the machine, safety features offered by it and the commended the Hawkeye grapple system. This grapple carriage was very capable, extracting 6-7 tonne stems in Opotiki. Ease of use was also a highlight, making it easy to teach a new operator to use the machine.

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Introduction

Many plantation forests in New Zealand are on steep terrain, but also the harvesting of smaller woodlots is becoming more prevalent (Raymond K. , 2010). This is also true in other parts of the world such as in Japan (Sakai, et al. 2013), Canada (Gingras, 2013), and Scotland (Tuer, et al. 2013). To this day the most effective way of conducting steep terrain harvesting is using a cable yarding system. Harvesting is one of the biggest costs in managing a forest and employing cable yarders in smaller woodlots can prove to be extremely costly. This is due to high costs associated with setting up the cable yarder and smaller woodlots not having the required wood volume to justify the frequent shifts (Stampfer, et al. 2006). To reduce this there has been many studies done to figure out the best way to do steep slope harvesting in a cost effective and safe manner (Visser, et al. 2014).

Excavator-based yarders, also called Yoaders, are built using excavator bases, attaching a tower to the top of the boom, boom end or on the base machine and using two or three drum winches (Torgersen & Lisland, 2002). Excavators are in in abundance throughout the world due to construction, farming and forestry making them a good base machine (Talbot, et al. 2014). Excavator-based yarders can be smaller, more stable due to being lower to the ground, and the use of the boom to stabilise it when needed, hence typically not requiring guylines for stability. This makes their relocations quick and works well when under space restrictions. Even though these machines have their advantages, not many manufacturing companies make standalone excavator-based yarders.

One company that does build excavator-based yarder systems is the New Zealand based Electrical and Mechanical Services Ltd (EMS). The company's workshop is based in Rotorua and they have built and shipped approximately 60 machines that are working throughout the world. In terms of the manufacturing process of the Harvestline, the client can provide their own excavator (with a 30+ tonne base) or EMS will acquire the base machine. EMS will replace the counterweights on the base machine and the winch kit will be attached to the machine. Removal of the counterweights and the installing of the winch kit results in approximately the same weight, and hence has little effect on the stability of the machine. A collapsible tower is be added to the boom arm. EMS have also designed a 'Hawkeye' grapple carriage system that is suited to the Harvestline.

As the Harvestline is a fairly new yarder system there has been no studies done on it (Ellegard, 2021). As such, this project completes a series of time studies to examine the productivity and capabilities of the Harvestline working in different stands and different terrain conditions. To do this EMS provided contact information for three crews that operate the EMS system:

1. Roxburgh contracting working for Wenita Forest Products in Waihola, south of Mosgiel.
2. Harper Logging working in the Kaingaroa forest for Timberlands.
3. STR logging working in a 1000ha woodlot in Opotiki, managed by Dodd forestry limited.

The following literature review section will outline existing literature to better understand steep slope harvesting, steep slope harvesting methods, and usage of smaller excavator-based yarders and advantages of using smaller excavator-based yarders.

Literature Review

According to Kuhmaier, et al. (2019) mountainous forests represent 23% of the total earth forest cover. A study done in Japan mentions that 50% of forests are located on slopes exceeding 25 degrees (Sakai, et al. 2013). A Canadian study discuss the need for better extracting equipment to extract on slopes greater than 40% (Gingras, 2013). Some other countries that are discussing the need for better steep slope extracting systems are Scotland (Tuer, et al. 2013), South Africa (McEwan, et al. 2013) and Ireland (Devlin & Klvac, 2014).

As for the New Zealand context, we harvested around 23.5 million cubic meters of wood and much of this is in steep and difficult terrain (Visser, et al. 2013), and this has increased to over 30 million m^3 in 2020 (NZFOA, 2020). 58% of the forests pending harvest were on slopes greater than 20 degrees (Raymond, 2010). As shown by Kuhmaier, et al. (2019) the main bottleneck in carrying out the safest possible harvest on these slopes have been the need for better and safer steep slope harvesting/extracting systems and to minimise the cost associated with operating state of the art equipment.

The basic yarder operation is to suspend the log partially or fully in the air and use a set of cables to extract the log from the cutover (Heinimann, et al. 2006). Some factors that affect the performance of a cable yarder are stand density, log size, extracting distance, slope, grapple configuration used and presentation of logs on the cutover (Devlin & Klvac, 2014). A combination of these factors decides the productivity and the increased safety provided by cable yarders.

One of the most important factors that determine the safety and the productivity offered by cable yarders is the rigging configuration used. Grapple carriage configurations can be classified as choker setters or mechanised grapple (Delvin & Klvac 2014). Choker setters working on manually felled cutovers can attach more trees compared to a grapple carriage, increasing production per cycle, but also bring down the utilisation of the machine and increase costs (Malietoa, 2014). Choker-setters are at risk of harm when working in the cutover, as seen on Figure 1, an abstract from lectures by Visser (2021). While manual felling and attaching logs has been the only way to carry out operations in steeper terrain in the past, especially when simply trying to minimise cost (Bentley, et al. 2005), mechanised grapples offer increased safety.

Table 1 – Job at time of accident

Operation	Number	Percentage
Felling	39	41%
Breaking out	13	14%
Extraction	11	12%
Skid work	9	10%
Trimming	5	5%
Maintenance	5	5%
Road use	5	5%
Moving Plant	2	2%
Loading	3	3%
Helicopter op	1	1%
Unknown	1	1%

Figure 1: Job at time of accident in forestry (from 2011 data).

An important factor that determines the level of productivity and safety of a cable yarders is the method of felling. Study carried out by Holmes (2017) show that manually felled logs result in the lowest productivity while bunched stems and stems fed into the grapple resulted in higher productivity. This is understandable due to manually felled logs having the potential of falling outside of the optimum yarding corridor as this was evident on my three studies. Another safety reason for lower utilisation is due to choker setters having to clear out of the slope before the inhaul can take place (MBIE, 2012). As opposed to choker setting some advantages of mechanical felling and extraction by mechanised grapple are that its safer, higher utilisation of machine and does not look as messy compared to a manually felled cutover. This last point is becoming extremely important due the public perception associated with forestry (Figure 2).

Figure 2: Mechanically felled trees, ready to be extracted by mechanised grapple.

Looking at the importance of state of art cable yarders, there have been many experiments done to develop and upgrade ground-based extracting systems. However, the cable yarder is still the best machine to carry out steep slope harvesting (Talbot, et al., 2015) and used worldwide due to safer operations and less soil disturbance (Kühmaier, et al., 2019). This is as opposed to a ground-based machine moving up and down the slope multiple times (Labelle & Jaeger, 2011). Another study done in south China, where ground-based machines couldn't be used due to 20% slopes and the resulting soil disturbance, Hoffmann, et al. (2013) assist in validating these claims.

Forestry around the world is moving into steeper yet smaller woodlots (Gingras, 2013). Within this new context, large cable yarders become too costly to operate (Visser, et al. 2014). This is due to them being expensive and time consuming to set up, and the smaller volume of a woodlot not being enough to justify the costs of relocating and setting up the yarder. Survey of yarding companies done in the Italian alps showed that majority of yarders used are tractor based due to the lack of logging infrastructure and related costs in using larger yarders (Spinelli & Magagnotti, 2013).

In comparison, the T-mar Log Champ is quite a large machine with a high centre of gravity (figure 3). The high tower provides adequate deflection but needs to be tied back using guy lines. Setting up of guy lines can take up to 6 hours and be very costly (Stampfer, et al. 2006) and Sakai, et al. (2013) noted forest workers did not like rigging guy lines. This reduces the machines utilisation and increases its cost (Visser, et al. 2015).

Figure 3: T-mar log CHAMP

To tackle issues such as smaller woodlot sizes, insufficient forestry infrastructure, decrease costs and improve profitability in forest operations many countries such as Scotland (Tuer, et al. 2013), Japan (Yoshimura & T, 2013), Ireland (Devlin & Klvac, 2014), America (Largo, et al. 2004) and New Zealand with the Harvestline have looked into and developed excavator-based yarders. It is important to note that there are many smaller guyed and unguyed yarders in existence (McMonchie, 1979) and (Liley).

A productivity study done by Delvin & Klvac (2014) on an excavator-based yarder with a choker setter used to extract biomass noted decrease productivity, shorter extraction distances and they found the logs couldn't not be extracted to the flats of the landing due to limited tower height. To remedy this situation stems were extracted to the top of the slope and processor used to pull logs up. This was also seen during this study in Mosgiel where an excavator with a grapple was used to pull the logs up and stop them from sliding down the slope (Figure 4).

Figure 4: Excavator working with the Harvestline to shift stems up the landing.

Evaluation on two excavator-based yarders in Scotland were done by Tuer, et al. (2013). First yarder was the Scottish "standard" Daewoo 220 and the second one being the Volvo 360 with an improved hauling-in mechanism. The second machine showed greater operability on steeper slopes, the first machined hauled in more volume and it is important to note that there was a significant variation of volume hauled by the first machine (0.2 – 10.9 t) compared to (0.5 – 6.0 t) of the second machine. These tree sizes are extremely large compared to the average New Zealand tree size. It is important to note the use of remotely operated chokes, eliminating the need for the yarder operator to get out and unhook the stem. Most carriage systems are moving towards mechanisation allowing for improved safety and better utilisation (Hawkeye, n.d.).

A study done by (Yoshimura & T, 2013) on swing yarders outlines that most Japanese swing yarders use excavators as the base machine. This study found that 28.4% of the whole cycle time of the yarder was spent rotating and piling logs. This could’ve been eliminated by using a grapple excavator to do the shifting and piling work, possibly increasing yarding productivity by 31.6%. There was a similar requirement to shift and pile logs for the Harvestline in all three of the studies, which was remedied by using a grapple excavator to shift logs up to the processor.

Talbot, et al. (2014) reported on an excavator-based yarder with processing capabilities, pointing out that the outrigger boom and counterweights allow an excavator-based yarder to work without guy-lines. Outlining some of the advantages of not having guy lines; they work well under space restrictions and allow for other machines to work in close proximity, as well as working well in smaller corridor woodlots due to the ease of moving the yarder.

A productivity study carried out by Largo, et al. (2004) on excavator-based yarders in Idaho showed some promising aspects of the concept. They found that these machines took significantly less time to move between different corridors. On average, one machine had a cycle time of about 4.35 minutes, this is slightly higher to that of the Harvestline extracting at a slightly longer distance (1.3 minutes). This study also outlined the feasibility of using an excavator-based machine in smaller settings, smaller woodlots and when the initial capital is low.

Engelbrecht, et al. (2017) had a similar landing set up to that of the Harvestline study, with excavators close to the yarder moving stems away. For this study data was collected over a period of a year and is relatively accurate due to the inaccuracies found in smaller time studies not existing. Making this study an ideal candidate to compare my time study on the Harvestline to.

Another excavator-based yarder machine that is available in New Zealand is the Alpine shovel yarder and Forest Growers Research did a study on this (Raymond & Hill, 2018). This study mentions the increase in cable yarding costs and the need to choose harvesting methods carefully to reduce costs.

In a Norwegian study done in order to find the most suitable excavator-based yarder concept, Talbot et al (2014) outlines some considerations made by contractors and forest managers when choosing a yarder. Some of these preferences were expanding yarding distance, extra stability, did not require retaining the use of the excavator bucket but it was surprising to see that contractors or forest managers weren’t concerned about the capital costs. This is understandable due to the simple fact that good machines tend to last and get work done effectively with lower maintenance costs.

According to Ellegard (2021) there is a Harvestline working in the Kaingaroa forest on relatively flat ground. This was due to the sensitivity of the soil on site, and he also mentioned the progression of the Harvestline to being the “go-to Kiwi light yarder” to be used on hard and technical terrain. The article mentions that the system works well under “good settings”, this is a bit unsettling as we would want the machine to work well in all terrain. This contractor also seems to enjoy the flexibility in using the excavator bucket when needed and the author outlines the quality of the finish and the entire build as well as newer upgrades made to the machine. It is important to note that this machine is pulling in 7.0 tonne stems, which is high by New Zealand standards. EMS is carrying out specific work for this crew, showing EMS's availability to work with their customers. This article also points out to the availability of GPS on the Hawkeye grapple, this could be very important in recording and studying data in the future.

Objectives

Three Harvestlines in different settings will be studied to find out the capabilities of the machine, to compare against existing yarders and to understand the feasibility of using this new cable yarding system to carry out harvest operations.

This information will allow the forestry industry to understand the capability potential of smaller excavator-based yarders such as Harvestlines in cable yarding operations

Methodology

This study is to be performed as a time study with a stopwatch looking at one machine in the harvesting operation. The machine being the Harvestline yarding system. To do this I will be timing every work cycle, a work cycle is the carriage leaving the landing and coming back to the landing with a stem. To better understand where the most time is saved or lost I further divided this work cycle into work elements. They are as follows,

- **Carriage out**
  This is the carriage leaving the landing until it is directly above the stem that's to be picked up, this element starts when the carriage is leaving the landing and ends when the carriage is dropped down to hook on to the stem.
- **Carriage hook on**
  This is the time take for the mechanised grapple to find the stem and hook on, this element starts as soon as the carriage is dropped to hook on to stem and ends when the carriage starts to move in.
- **Carriage in**
  This is the time taken for the carriage to move back to the landing, this element starts as soon as the carriage is moving back on to the landing and ends as soon as the carriage stops at the landing.
- **Unhook**
  This is the time take to drop the log in the landing, this element starts as soon as the carriage has arrived at the landing and all horizontal movement has stopped. This element ends as soon as the carriage starts moving out of the landing.

These four element times are added up to produce the total cycle time.

As well as each element time, I recorded the distance carriage moved out to, estimated diameter of the stem, whether each was a full stem or a top and any delays that occurred. Comments section was used to classify delays into mechanical, operational and other as well as making other comments. Example data entry sheet is shown below in Appendix 1.

As well as taking time on a stopwatch, a GPS unit will be attached to the carriage to gather data on the movement of the carriage and this will allows better understanding of the velocity of the carriage as it goes out and when it comes back with a stem.

To gather this data, I need go to a harvest site that is currently operating a Harvestline. Locate myself somewhere I can see the yarder, the entire corridor and the tail hold. It is also paramount that I am well away from the machines operating to ensure my safety as well as to not hinder in any of the operations. In terms of mounting the GPS device, this will be done prior to the work day starting, GPS unit will be taped on to the carriage and removed from the carriage at the end of the work day.

Data gathered will then be transferred on to Microsoft Excel. Where I will calculate:

- **Average time taken to complete each element.**
  Calculated using the average function within excel.

- **Average cycle time.**
  Calculated using the average function built into excel.

- **Average size of the stem extracted.**
  Harvestlines have a very short cycle time and it hinders operations to go up to the landing and record stem sizes for each stem. I will measure about 20 diameters of extracted stems before work starts and 20 stems at the end of the day.

  The following formula will be used to calculate the volume. 0.9 is used as the wastage factor, assuming 10% is lost during processing.

$$Volume = \frac{(\frac{Diameter}{10})^2}{10} \times 0.9$$

- **Average extracting distance.**
  This is measured using a range finder. One measurement will be taken from the tail hold and one from the yarder. This will be done at the start of the day to avoid disrupting operations.

- **Productivity.**
  Calculated by multiplying the average stem size by the number of stems extracted.

- **Productive machine hour (PMH).**
  This is the number of hours the machine is in carrying out its primary task. Calculated as shown below.

  PMH = SMH – Delays

  SMH = Scheduled machine hours.

  Delays = Time taken for any delays that occurred.

- **Productivity per Productive machine hour (PMH).**
  This is calculated by dividing the productivity by the hours the machine is in use.

The GPS data will be added onto ArcMap. This is a good way of visualising the carriage moving in the corridor, clearly see the tail hold shifts. Also produce accurate distance measurements. As well as producing velocity results for each element within the work cycle.

- **Velocity of the carriage as it goes out and when it comes back in.**
  The KML files from the GPS device will be converted into Excel files. These Excel files show X and Y coordinates. Then the KML file will be displayed in Google Earth, this serves the purpose of finding starting points and following each recorded GPS point as the carriage goes out or as the carriage comes back in.

The start and end points need to be established in order to take measurements from the GPS data. For example, for the carriage going out I will use the starting point as the last recorded point before the GPS is moving out down the slope (representing the carriage starting to move), for the end point I will use the GPS point where the carriage stops.

Knowing these two points. I will calculate the distance travelled as shown below.

$$Distance = \sqrt{(y_2 - y_1)^2 + (x_2 - x_1)^2}$$

Distance calculated will be divided by the time taken for the carriage to travel this distance as shown below.

$$Velocity = \frac{Distance}{Time\ at\ final\ point - Time\ at\ starting\ point}$$

Three different Harvestlines will be studied and respective productivity results will be compared against each other to better understand the capabilities and obstacles faced by the Harvestline. These productivity figures will then be compared to other studies done to examine and better understand the feasibility of using a Harvestline to carry out cable yarding operations.

Site description

As mentioned above three different Harvestlines were studied and within this section I will provide a site description for each site.

Mosgiel

This study was done in Waihola, 20 minutes south of Mosgiel. Forest managed by Wenita Forest Products. Forest consisted of pruned *Pinus radiata.* The average stem volume was 2.0 tonnes. The harvesting crew was Roxburgh Contracting; they are a fully mechanised crew. However, stems extracted on the study site was manually felled due to the self-levelling feller being out on repair and maintenance.

Site layout

Average slope was 30 degrees and the tail hold was located 210 m from the yarder, pulling over broken terrain. Following figures show extraction corridors and the site as seen from the tailhold side.

Figure 5: Harvestline working from right to left (Arrow). Note the presenting of butt ends of cut stems.

Through discussion with Blair the Harvestline operator, it was apparent that selection of the yarding corridor considering the presentation of butts is important to ensure that logs are pulled up in the most efficient manner.

Figure 6: The extracting corridor as seen from the road, on which the tailhold was located. Another important aspect seen here is the broken terrain, through which logs were pulled over. Note the presentation of butt ends of felled stems.

One difficulty that arose from this corridor was that the wires snagging on other stems and stumps at the top of the ridge (circled). This caused the cables to jump up after they were freed, having the potential for some cable rub, causing damage to the cables.

Figure 7: Hawkeye grapple system extracting a stem.

Once stems had been pulled up, there was a tendency for some of these pulled stems to slide back down due to the Harvestline operating right at the edge of the ridge and slash on the slope. However, these stems would only slide about 5-10 m off to the side of the yarding corridor and the operator could easily swing the yarder in either direction to pull these logs back up.

Machines used

The Harvestline base machine was a Sumitomo SH460 HD and the tailhold used was smaller CAT machine.

Figure 8: Harvestline operator, Blair with his machine.

Figure 9: The operator setting up the tailhold machine after a shift.

Rotorua

This study was done in Kaingaroa forest, managed by Kaingaroa Timberlands Ltd., 40 minutes southeast of Rotorua. The forest consisted of pruned *Pinus radiata*. The Average stem volume was 1.9 tonnes. The harvesting crew was Harper Logging. Felling was completed manually at this site. This crew was also responsible for pulling out slash from the gully.

Site layout

The average slope was 30 degrees and the tailhold was situated 150 metres from the yarder. The following figures show the operation as seen from an adjacent ridge and the tailhold ridge.

Figure 10: the extraction site and the first setting.

Extractions were carried out on the face slope, moving from right to left (arrow). Then moving onto the second setting, which from where this photo was taken.

Figure 11 shows the second setting. Extraction moved from left to right (arrow). The operator, Hemi was working from the immediate front and then gradually clearing stems out to the tailhold. One distinct advantage seen was that logs did not snag on other logs and it was an easier extraction.

Figure 11: Second setting, note the presentation of stems.

Figure 12: Slope after extraction

Machines used

The Harvestline base machine was a Doosan DX 380 LC.

Figure 13: The machine operator, Hemi with his machine.

Figure 14: Tailhold machine in action.

Opotiki

This study was done in a 1000 ha woodlot managed by Dodd Forestry Ltd. This site was located approximately 15 minutes south of Opotiki and consisted of pruned *Pinus raidata.* The average stem volume was 2.3 tonnes. STR Logging Waiotahi was the harvesting crew, again felling manually.

Site layout

Average slope was 35 degrees and the tailhold was situated 440 m from the yarder. The following figures show the site and landing as seen from the ridge on which the Harvestline was located, from the access road and from the cab.

Figure 15 shows prior harvested area. To carry out this extraction the Harvestline was located where this photo was taken, all stems were either pulled down or up as needed. The tail rope was attached to stumps on the opposite ridge.

Figure 15: Prior harvested area.

Figure 16 shows the current extraction corridor and a bulldozer was used as a tailhold situated 440 metres away from the Harvestline (starred). Extractions were carried out from right to left (arrow).

Figure 16: Extraction corridor.

Figures 17 and 18 show the landing. Landing space is extremely limited but STR logging managed to extract all the area shown in Figures 15 and 16 via this landing. Due to this unique landing layout, grapple excavators were used to shovel logs down to the processor.

Figure 17: Landing as seen from the top where the Harvestline was located.

Figure 18: Operation as seen from the access road.

Machines used

The Harvestline base machine was a Komatsu PC 400 LC with a custom cab by EMS Rotorua. Tailholds were a tree stumps and a Bulldozer in setting 1 and setting 2 respectively.

Figure 19: Machine operator, Fletcher with his machine.

Results

Three different Harvestline yarders were studied at three different locations and 1030 cycles were recorded. Breaking down the total cycles recorded, I spent 3 days and recorded 353 cycles in Mosgiel, spent three days in Rotorua and recorded 431 cycles and finally spent two days in Opotiki and recorded 246 cycles. For the ease of presenting the data collected I will separate the results section by the three study sites.

Mosgiel

The machine used in Mosgiel was the Sumitomo SH460. Average piece size over the three days was 2.0 tonnes, average cycle time was 1 minute 22 seconds, average extraction distance was 105 m and average productivity of the machine was 86 t/PMH. Table 1 shows the average time taken to complete each element and the corresponding 5th and 95th percentile times.

Table 1: Numerical values calculated.

	Average	**5th percentile**	**95th percentile**
Distance (m)	104	35	180
Cycle time (s)	82	37	132
Each element within the cycle			
Out haul time (s)	25	10	40
Hook on time (s)	24	10	55
In haul time (s)	29	7	53
Hook off time (s)	4	2	7
Productivity (t/PMH)	101	41	197

When interpreting numbers from Table 1 we can follow along with a certain distance. For example, if I were to extract a stem at 104 meters, the average cycle time would be 82 seconds. The average out haul time would be 25.

As shown in table 1, carriage out took approximately the same amount of time as the hook-on time due to the operator slowing down the carriage going down to focus on the cameras and look for logs that might be under slash. Hook on time of 25 seconds could be attributed to the operator looking for a second or third log he can bunch and grab and due to scanning the tree length to make sure there are no snags that can break the stem that is being pulled up. 29 seconds taken to pull the carriage in could be attributed to the extra load exerted on the machine. Hook off time is very low and this is where most of the time was gained back. This is due to the operator being able to quickly release the grapple and the grapple excavator working right next to the Harvestline swiftly grabbing the stem and moving it up the landing. Looking at Table 1, time taken to send the carriage out and to bring the carriage back in, fluctuates up when the extraction distance goes up and fluctuates down when the extraction distance is shorter. However, it is important to look at the variation between the average hook on time, average hook off time and respective 5^{th} and 95^{th} percentile numbers. These seldom fluctuate with varying lengths, rather they fluctuate with the immediate terrain and obstacles found on the ground. The fluctuation in hook off time is due to Blair waiting for the grapple excavator to return from performing a different task. This happened as a result of logs sliding down and the Harvestline operator would at times hand the stem from the carriage to the grapple excavator. Note that the productivity figures shown in Table 1 are the productivity calculated per each productive cycle.

Figure 20 shows the cycle time that was taken to reach a certain extraction distance. We can see that longer the extraction distance, longer it is going to take to extract the stem.

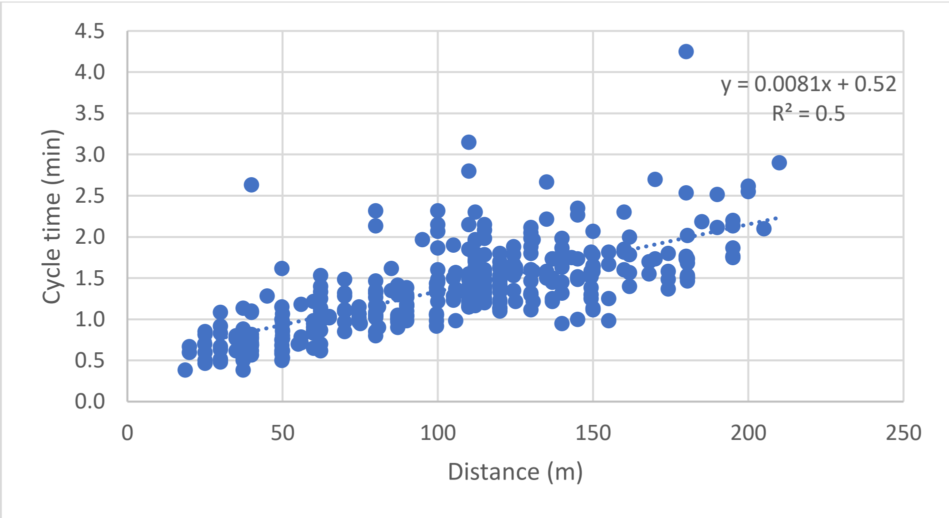

Figure 20: Cycle time in minutes Vs the distance in meters.

As shown in Figure 20, we can use $Cycle\ time = 0.52 + 0.008\ \times Dist$ to figure out time taken to extract stems at a certain distance.

Now I will break down the overall cycle into each element and present this data. Figure 21 shows the time taken for the carriage to go out to a certain extraction distance.

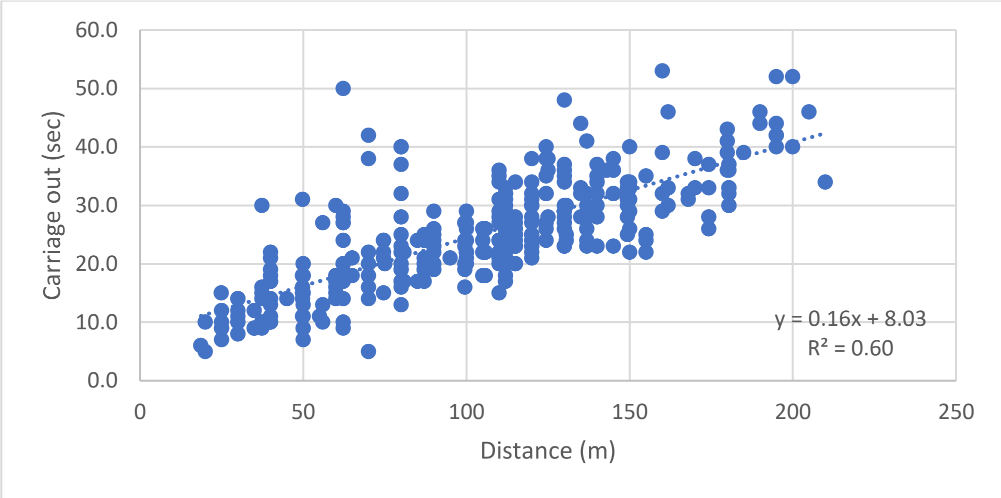

Figure 21: Time taken for the carriage to go out Vs the extraction distance.

Figure 21 shows that time to send the carriage out increases with increasing distance. This relationship is represented by $Carriage\ out = 8.04 + 0.16\ \times Dist$.

Figure 22 shows the time taken to lower the grapple and hook on to stems at certain distances.

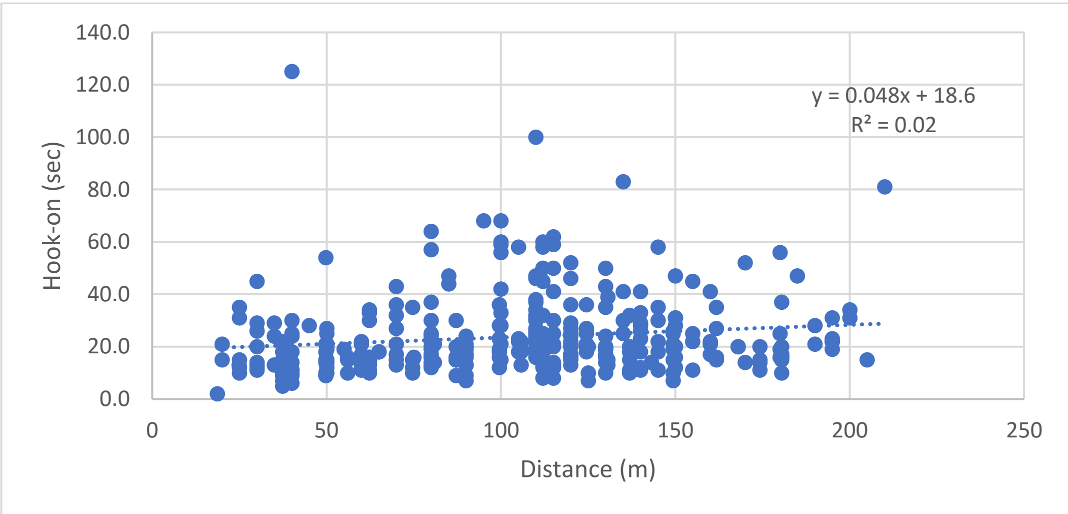

Figure 22 Hook on time in seconds Vs the extraction distance.

Comparing the time taken to hook on to time taken to send the carriage out, it is visible that there isn't a strong increase in time taken to hook on at longer distances. This is due to the hooking on element depending on the immediate surrounding of the stems. For example, trying to pick up two stems, clearing obstacles etc. Most variation in hook on time was seen in the middle of the extraction corridor, due to the middle of the extraction corridor being in gullies and the carriage deflected from side to side the most here.

Figure 23 shows the time taken for the carriage to return after extracting a stem at a certain distance.

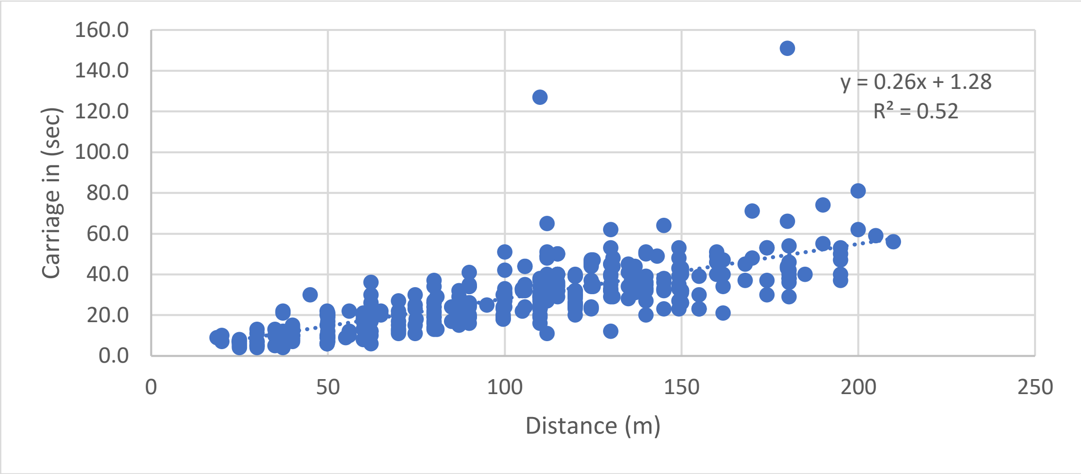

Figure 23: Carriage in Vs the extraction distance.

Here we see a strong correlation between extraction distance and time taken for the carriage to return. Confirming that longer the extraction distance, longer it will take to return loaded. This is shown by the relationship, $Carriage\ in = 1.28 + 0.27\ \times Dist.$

Table 2 below shows the velocity of the carriage calculated using the GPS data. These velocities are divided into two sections for the ease of presenting. First being the carriage out, speed of the carriage as it moved out into the cutover prior to grabbing a stem. Secondly the carriage in, this is the speed of the carriage coming back to the landing whilst carrying a load.

Table 2: Velocities calculated.

Carriage out		
Minimum	1.2	m/s
Average	4.0	m/s
Maximum	6.0	m/s
Carriage in		
Minimum	0.9	m/s
Average	3.8	m/s
Maximum	6.3	m/s

As we would expect the speed of the carriage going out is higher than that of the carriage coming back. This is due to the operator being able to send the carriage down slope fast, almost as in a shotgun configuration. The lower speed of the carriage returning is due to being under payload. Looking at the maximum speeds, we can see that the carriage in speed is greater than the speed of the carriage going out. This could have resulted due to the operator keeping an eye out on the cameras looking for suitable logs on the way out. A higher maximum carriage in speed could also occur in an extraction cycle where tops instead of stems were pulled.

Three days spent in Mosgiel can be further divided into two settings. Figure 24 shows setting 1 as seen on google earth. Red rectangle is where the Harvestline was located. Yellow triangle shows where the tailhold excavator was located. Green circle shows the safety location chosen to be out of the way of the crew yet be able to see the whole operation. Average extraction distance in setting one was 107 metres. Blair spent 4 hours in this setting, extracted 189 stems, average piece size was 1.9 tonnes and the productivity was 91 t/PMH.

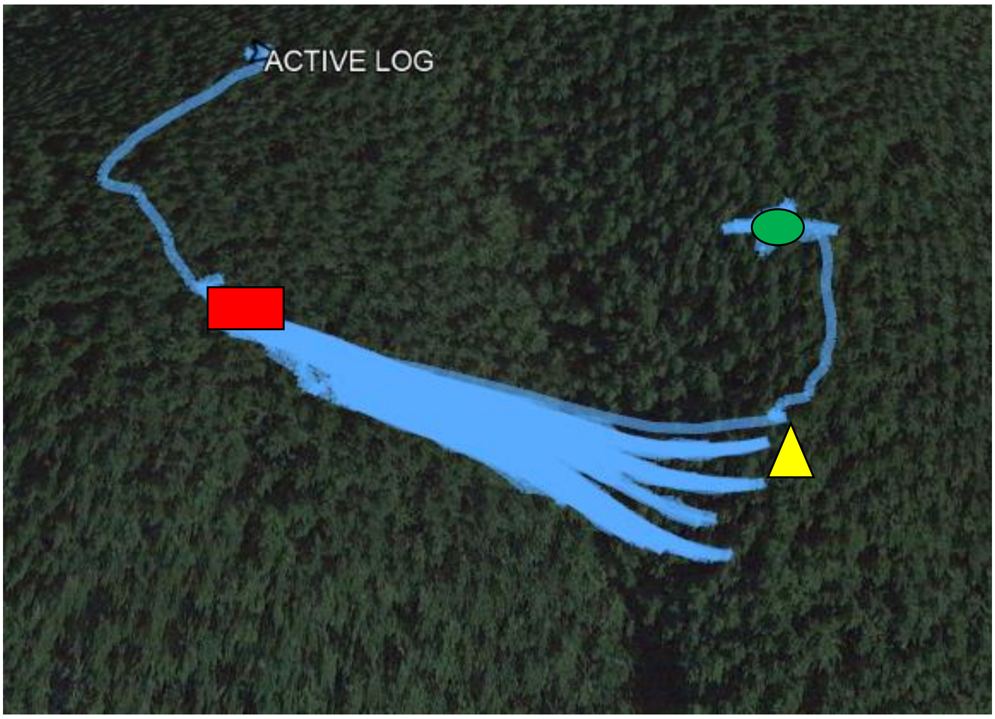

Figure 24: Setting 1.

Figure 25 shows setting 2 as seen on ArcMap. Average extraction distance within this setting was 100 meters. The Harvestline operator Blair spent 4 hours working in this setting, extracted 169 stems, the average piece size was 2.1 tonnes and the productivity was 85.3 t/PHM. In Figure 25, the yellow triangles show the tailhold moving down the road. Green circle showing my observation point and the red rectangle showing the Harvestline location.

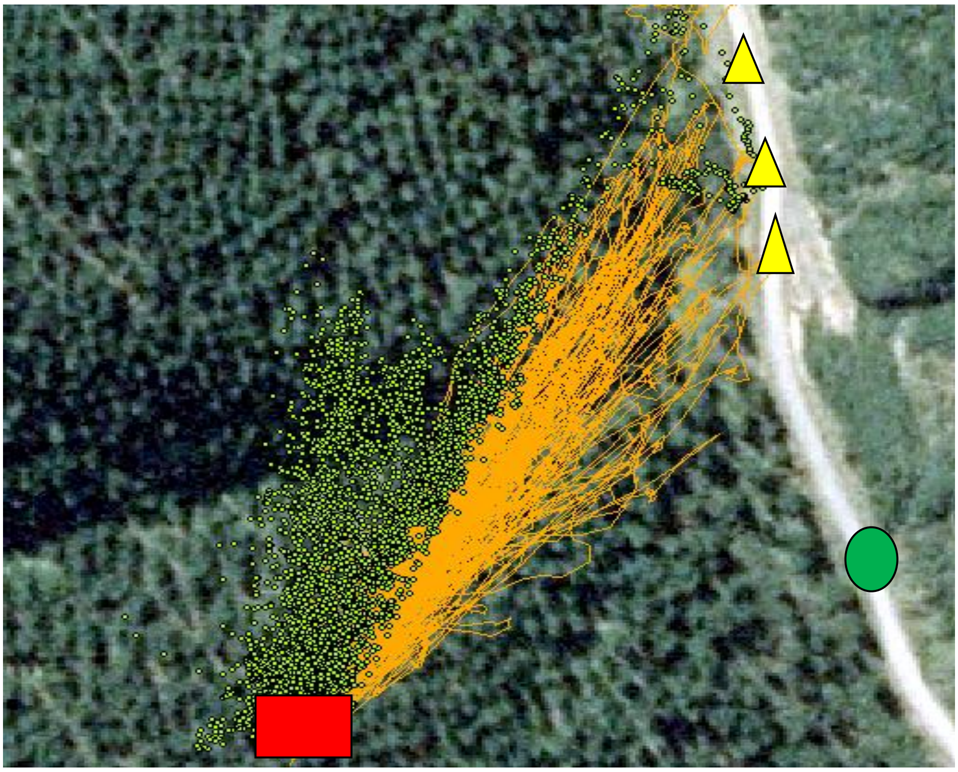

Figure 25: Setting 2.

Comparing setting 1 to setting 2. Setting two has a lower average extraction distance. However, a higher cycle time and this could have resulted due to pulling over broken terrain.

Delays

Utilisation rate for the three days was 57%. Two major delays occurred during the time of the study. First being a diesel pipe cracking on the carriage that took 2 hours and 24 minutes to fix. Which was remedied by cutting the hose end with the crack and reattaching the fresh end. The second delay occurred when the tailhold was being positioned for setting 2. This took 1 hour and 36 minutes. The tailhold excavator travelled an approximate 1 kilometre on a gravel road around a stand to get to the new setting.

Rotorua

The machine used in Rotorua was a Doosan DX 380LC. Average piece size over the three days was 1.9 tonnes, average cycle time was 1 minute 24 seconds, Average extraction distance was 96 meters and the estimated productivity of the machine was 76.7 t/PMH. Table 6 shows the average time taken to complete each element within the cycle and associated 5th and 95th percentile values.

Table 3: Numerical values calculated.

	Average	5th percentile	95th percentile
Distance (m)	89	40	140
Cycle time (s)	82	49	128
Each element within the cycle			
Out haul time (s)	24	11	40
Hook on time (s)	23	8	54
In haul time (s)	31	15	50
Hook off time (s)	4	2	6
Productivity (t/PMH)	83	0	165

Comparing Table 3 to the data from Mosgiel, we can see a good relationship building across all the data. As the extraction distance increase the time for the carriage to go out increase.

Like Mosgiel, Rotorua has a similar hook on time to the time taken to send the carriage out. As mentioned in the Mosgiel results this was due to the operator taking his time to observe, try grab another stem, clearing slash and clearing obstacles. This was more apparent in Rotorua, where the Harvestline operator was responsible for picking up a lot of slash from the gullies and sometimes had to remove broken stems and slash first before picking up the log. Therefore, the time taken to do that is reflected here. As expected the time taken to bring the carriage up to the landing was higher than the carriage out time. Comparing the productivity of Rotorua (76.7 t/PMH) to that of Mosgiel (86 t/PMH), Rotorua is lower due to the crew pulling up slash and broken stems that could not be cut into stems. It is important to recognise, even though the productivity number is lower Hemi and his Harvestline was doing their job as asked by the forest company. A 5th percentile productivity value of zero is the result of the operator pulling up tops and slash that cannot be converted into logs.

Figure 26 shows the overall cycle time compared to the extraction distance. This graph represents all three days spent in Rotorua. We can use the above graph to find the time taken to extract a stem or stems at a certain distance. This relationship is shown by $Cycle\ time = 0.1 + 0.004 \times Dist$.

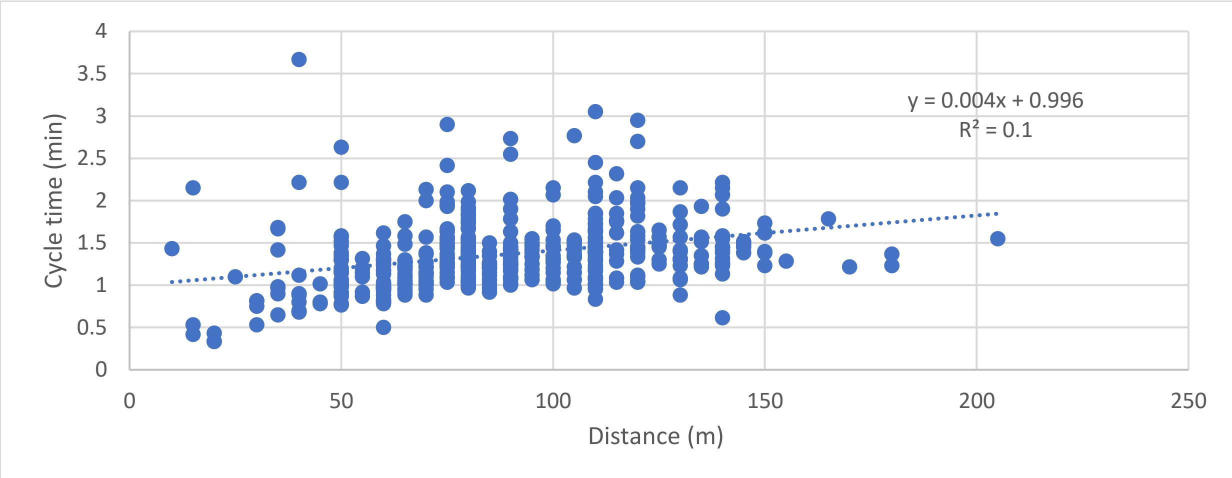

Figure 26: Cycle time in minutes Vs extraction distance in meters.

In the following figures I have broken down elements within the cycle for all three days spent in Rotorua. These times are presented against extraction distances.

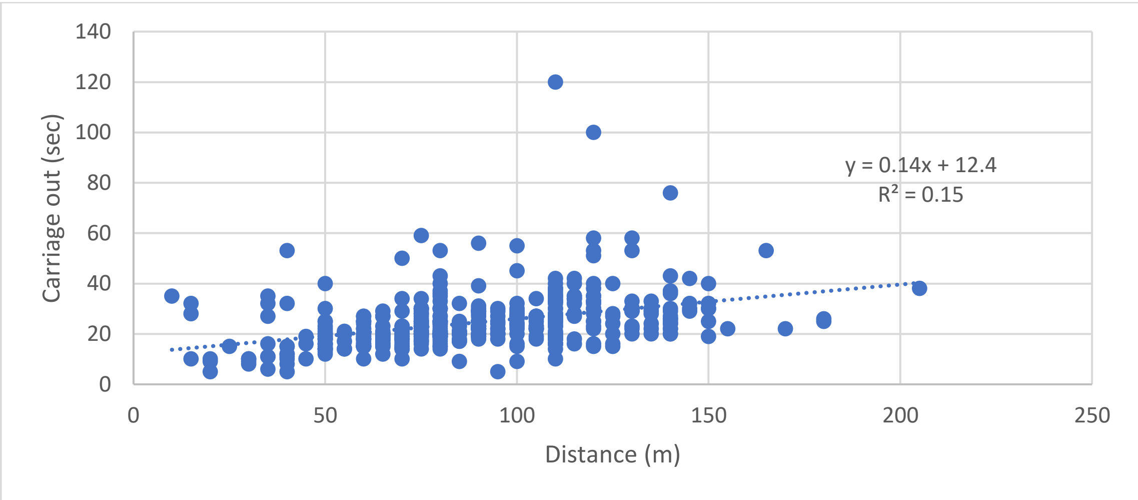

Figure 27: Time taken for the carriage to go out Vs extraction distance in meters.

Time taken for the carriage to go out a certain distance is represented by the relationship:

$$Carriage\ out\ time = 12.4 + 0.14 \times Dist.$$

Comparing Figure 27 to Figure 21 from Mosgiel, we can see that Mosgiel has a stronger a relationship in terms of time taken to send the carriage out and the extraction distance. Figure 28 below shows the time taken for the operator to hook onto a stem/stems.

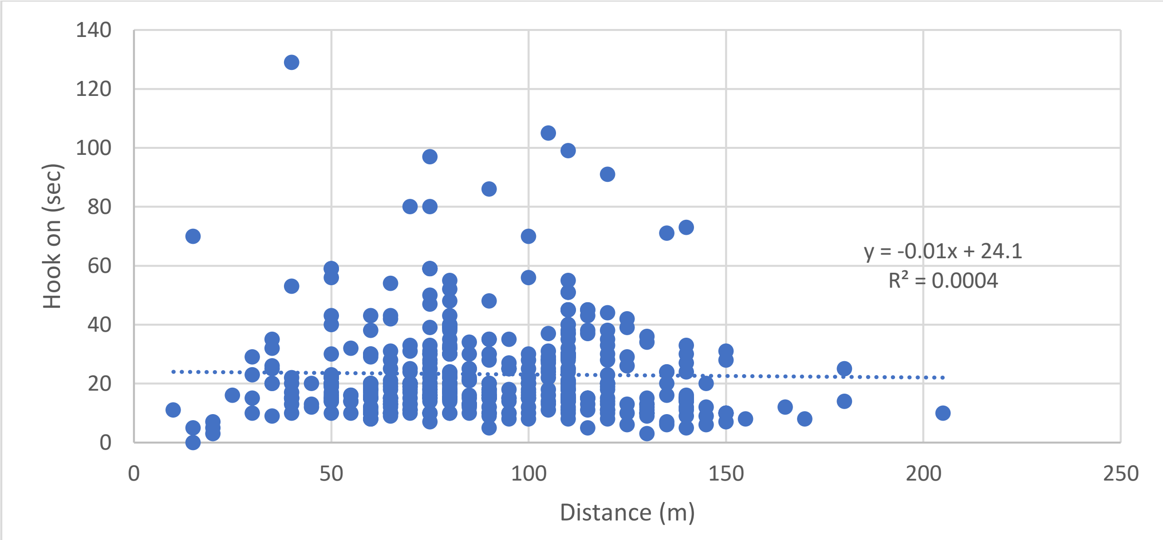

Figure 28: Hook on time in seconds Vs extraction distance in meters.

Relationship $Hook\ on\ time = 24.1 - 0.01\ \times Dist$ shows that as the extraction distance increases the hook-on time decreases. This is unusual but could be due to the tail hold operator guiding in the Harvestline operator to pick up logs at further reaches of the extraction corridor. However, this relationship could have resulted from error in recording time and due to being an extremely small margin off from being "same time taken to hook on at all distances". Looking at Figure 28, the most variation in hook on time was in the mid extraction corridor. Occurring due to the carriage moving side to side most here.

Figure 29 below shows the time taken for the carriage to return back to the landing after extracting a stem/stems.

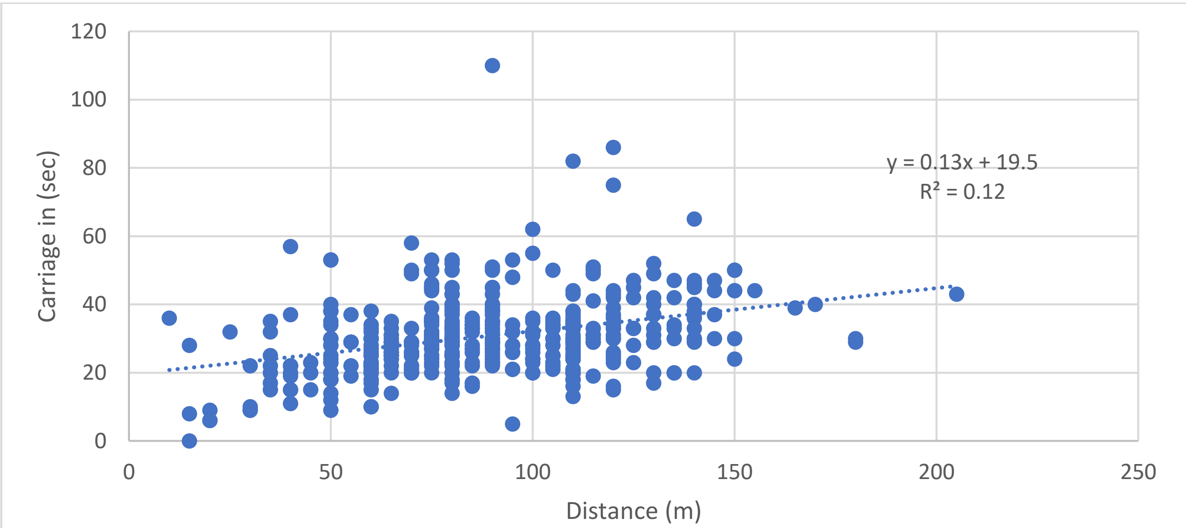

Figure 29: Time taken for the carriage to return Vs the extraction distance.

As expected the relationship $Carriage\ in\ time = 19.5 + 0.13\ \times Dist$ shows that as the extraction distance increase the time taken for the carriage to return increase. This is also due to the carriage returning loaded. Therefore, the heavier the load, the slower the carriage will return.

Table 4 shows the velocities calculated for this setting. Velocities were calculated using the GPS data.

Table 4: Velocities calculated.

Carriage out		
Minimum	0.3	m/s
Average	3.8	m/s
Maximum	7.2	m/s
Carriage in		
Minimum	0.3	m/s
Average	3.0	m/s
Maximum	6.1	m/s

These numbers show distinction between carriage going out empty and the carriage coming back with stems. The carriage slowed down due to the increased payload.

Time in Rotorua is divided into two settings. Figure 30 shows setting 1 as seen on ArcMap with the location of the Harvestline is shown by the red rectangle, tailhold positions are shown by the yellow triangles and my point of observing is shown by the green circle. Average extraction distance within this setting was 111 m, the Harvestline operator spent 3 hours on this setting, extracted 111 stems, average piece size was 2 tonnes and productivity was 74 t/PMH.

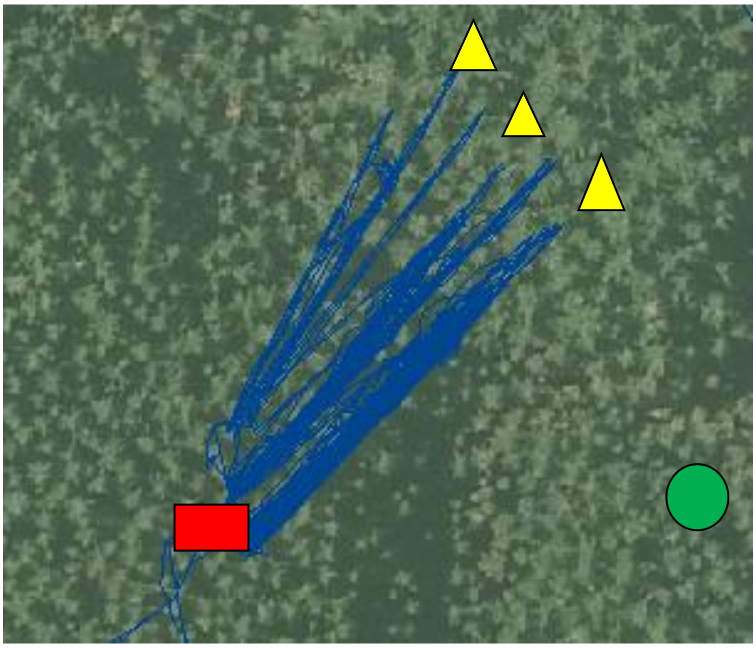

Figure 30: Setting 1.

Figure 31 shows setting 2 as seen on ArcMap. Yellow triangles show tailhold locations, red rectangle shows the location of the Harvestline and the green circle shows my observation point. The Harvestline operator spent 7 hours on setting 2, the average extraction distance was 80 metres, extracting 274 stems. The average piece size was 2.1 tonnes and the estimated productivity was 84 t/PMH.

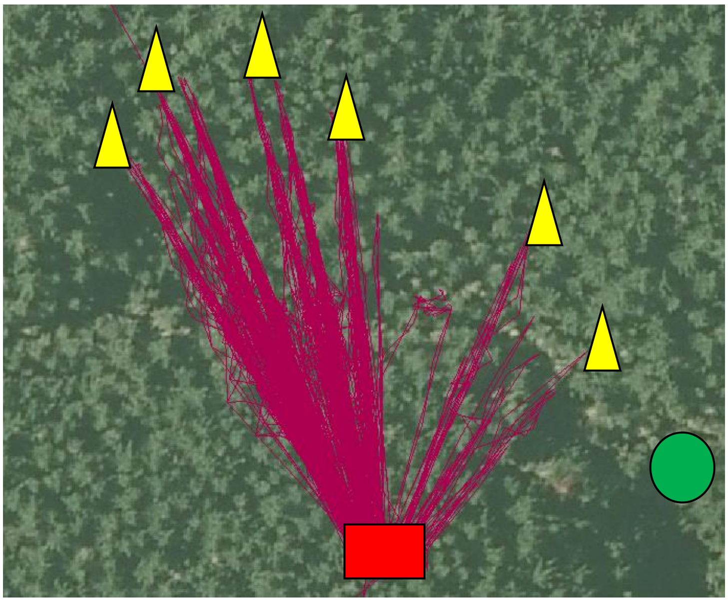

Figure 31: Setting 2.

Extraction distances were the shortest in this setting and this data fits well into the relationship between extraction distance and cycle time.

Delays

Utilisation for the three days was 50%. One major delay occurred during the study period due to the Harvestline repositioning to setting two. This lasted 1 hour and 12 minutes. This was an ordinary yarder shift except for a drone being used to send the straw line across to the tailhold. Lawrence Harper of Harper logging was using a fishing drone and a lighter straw line to pull the straw line of the Harvestline across to the tailhold machine. This was surprisingly efficient and took away the need to have an operator run across steep gullies.

Opotiki

The machine used in Opotiki was a Komatsu PC 400LC. Average piece size over the two days was 2.3 tonnes, average extraction distance was 181 meters, average cycle time was 2 minutes and 27 seconds and the estimated productivity of the machine was 58 t/PMH. Table 5 shows the time taken to complete each element within the cycle.

Table 5: Elemental time and productivity values.

	Average	5th percentile	95th percentile
Distance (m)	180	58	283
Cycle time (s)	148	63	243
Each element within the cycle			
Out haul time (s)	44	22	65
Hook on time (s)	32	10	75
In haul time (s)	68	20	123
Hook off time (s)	4	2	10
Productivity (t/PMH)	67	32	132

As might be expected, average carriage out and carriage in time increased due to the increased extraction distance. Time taken to bring the carriage in increased due to the increased payload of 2.3 tonnes compared to 1.9 tonnes (Rotorua) and 2.0 tonnes (Mosgiel). On average the hook-on time was also higher for Opotiki due to manually felled trees not being presented in the most ideal manner and difficult terrain. Lower productivity of 58 t/PMH compared to 76.7 t/PMH of Rotorua and 86 t/PMH of Mosgiel could have resulted from extracting from very long distances. Another reason for the delay could have been due to the Harvestline operator taking extreme care to prevent any cable rub and to exert the least amount of stress on the cables.

Figure 32 shows the cycle times for the two days with the respective extraction distance. The main difference here is the greater extraction distance compared to the other studies. Therefore, the higher cycle time resulting from it. The relationship between cycle time and the extraction distance is shown by

$$Cycle\ time = 0.87 + 0.01\ \times Dist.$$

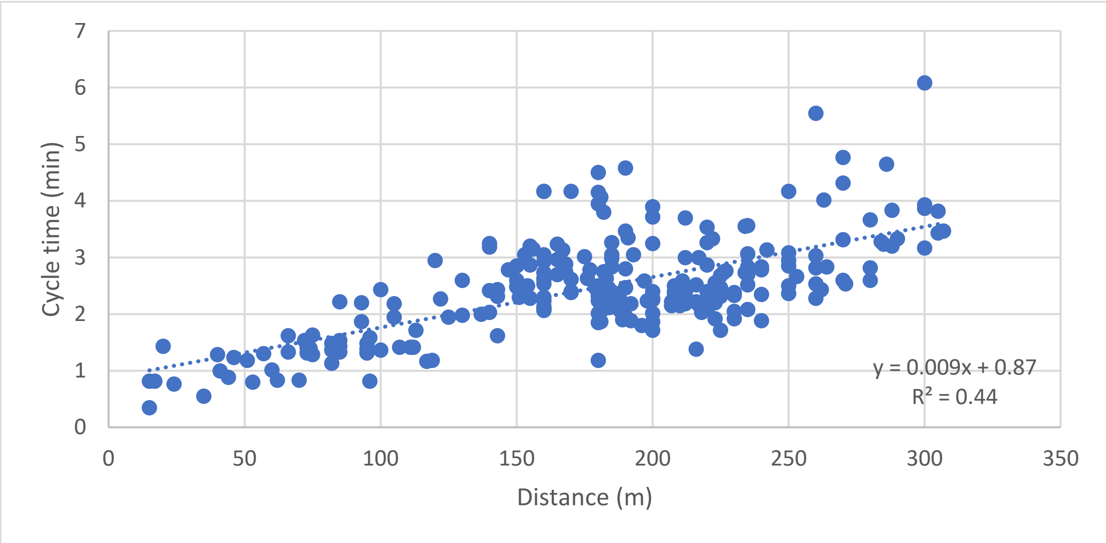

Figure 32: Cycle time Vs the extraction distance.

The following graphs show an elemental breakdown of this cycle time.

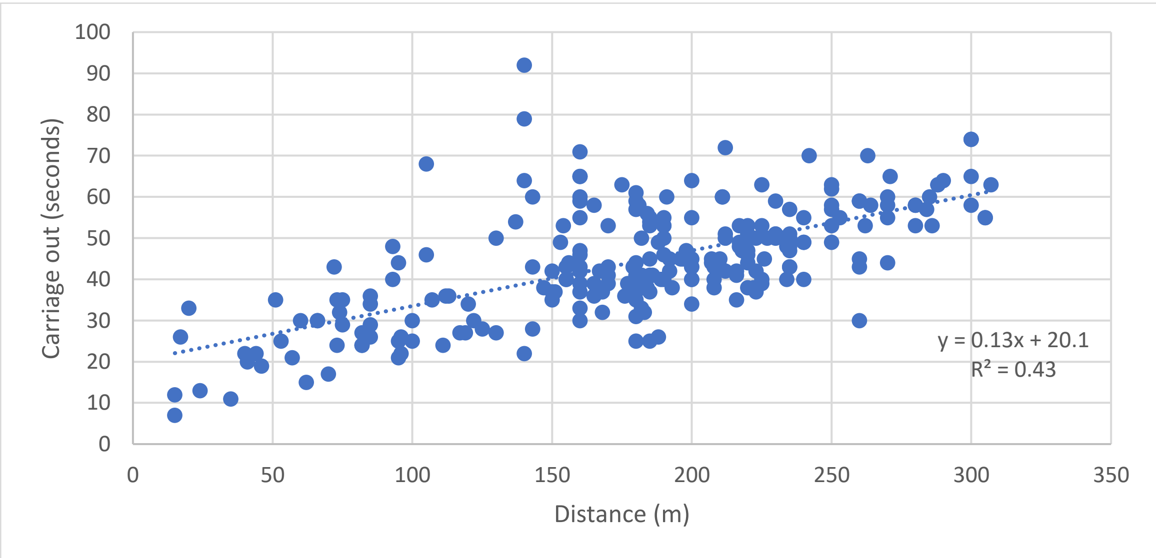

Figure 33: Carriage out in seconds Vs extraction distance in meters.

As expected, the time taken for the carriage to go out increases with the increasing extraction distance. This relationship is represented by $Carriage\ out\ time = 20.1 + 0.13\ \times Dist.$

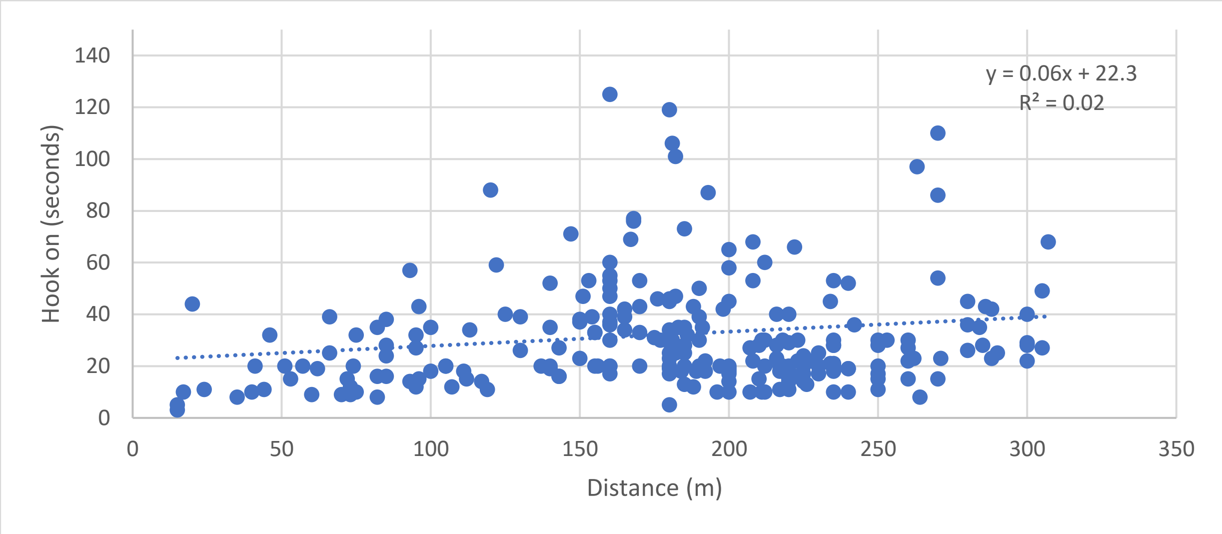

Figure 34: Hook on time Vs the extraction distance.

Higher hook on times could have resulted from increasing extraction distances due to not being able to directly see the stems. This was apparent in Opotiki where extraction distances were higher and the operator relied completely on the cameras on the Hawkeye grapple system. According to the operator these cameras work great but it is good to be able to see the carriage when picking up stems (an unaffordable luxury when pulling stems at such distances and in gullies). This relationship is shown by $Hook\ on\ time = 22.3 + 0.06\ \times Dist.$

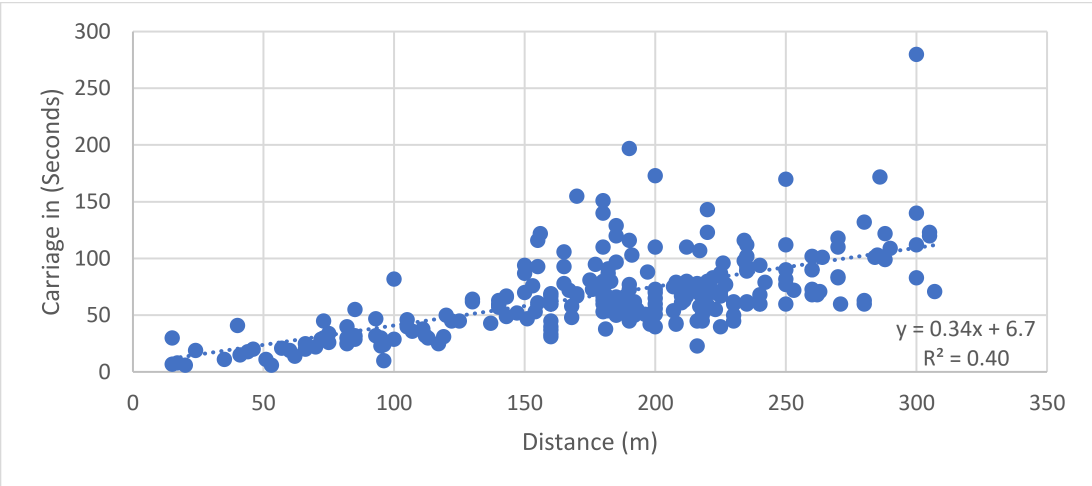

Figure 35: Carriage in time Vs the extraction distance.

As we would expect the time taken to bring the carriage back in increases with extraction distance and this relationship is shown by $Carriage\ in\ time = 6.70 + 0.34\ \times Dist.$

Table 6: Velocities calculated.

Carriage out		
Minimum	0.6	m/s
Average	4.0	m/s
Maximum	6.0	m/s
Carriage in		
Minimum	0.5	m/s
Average	2.8	m/s
Maximum	4.0	m/s

Comparing these values (Table 6) to the velocities of the two prior studies we can see that these values are lower. The speed of the carriage going out is similar to the carriage coming back in. This could have been due to the operator taking great care to prevent wires rubbing when the carriage is travelling unloaded, happening due to the tailhold being located far away.

Time spent in Opotiki can be divided into two settings. Figure 36 shows setting 1 as seen on ArcMap.

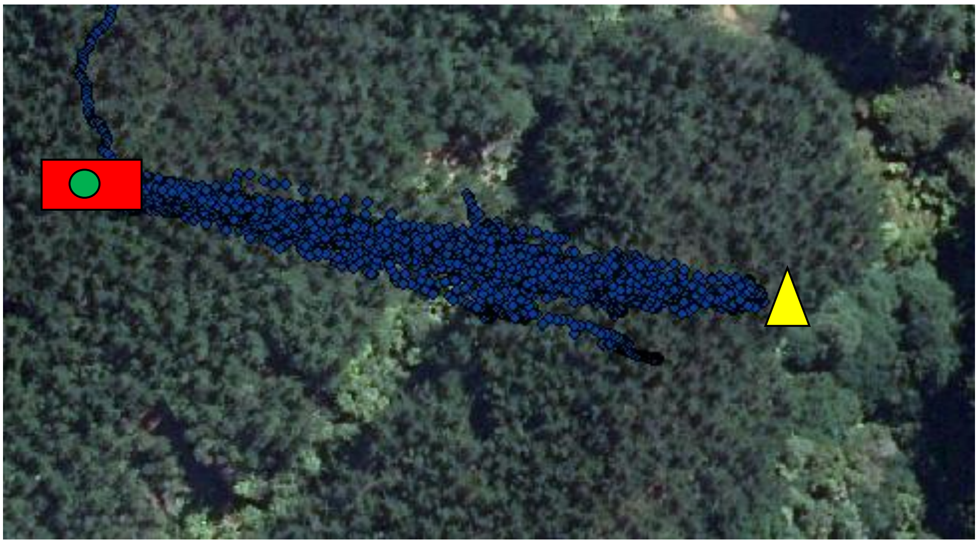

Figure 36: Setting 1.

In Figure 36, the red rectangle represents the position of the Harvestline and the yellow triangle represents the tailhold position. It is important to note that a tree stump was used as the tailhold for this setting, this is different to the previous two studies. The green circle represents my observation point and for this study I was in the Harvestlines' custom made cab. Hence the green circle inside the red rectangle. This was also different from the two other studies where the previous two crews did not have custom made cabs.

The Harvestline operator spent 2 hours and 22 minutes on setting 1, average extraction distance was 138 metres, he extracted 57 stems, the average piece size was 2.3 tonnes and the productivity was 56 t/PMH. Table 10 shows numerical data for this setting including cycle time, time taken to complete each element and associated 5th and 95th percentile values. These extraction distances are higher than both the other studies, hence complementing the overall relationship between cycle time and extraction distance well.

Figure 37 shows setting 2 as seen on ArcMap.

Figure 37: Setting 2.

The red rectangle represents the Harvestline, green circle shows my observation point and the yellow triangle represents the tailhold position.

The operator spent 4 hours and 10 minutes on setting 2, average extraction distance was 192 metres, extracted 198 stems, the average piece size was 2.3 tonnes and the productivity was 109 t/PMH. The Harvestline was extremely productive in this setting comparing to setting 1 and the two previous studies done. Setting 2 had the longest extraction distances of the whole study, therefore providing a good dataset for the extreme extraction distances.

Delays

Utilisation over the two days was 64%. Two major delays occurred during the time of the study. One being the tail shift to 440 m and the other due to the mainline snapping. Tail shift lasted 1 hour and 10 minutes and the Hawkeye grapple was used to send strops/D-ring locks to the bulldozer 440 metres away. Delay due to the mainline snapping lasted 1 hour and 30 minutes. The broken end of the cable was cut and a new attachment point was spliced on the spot.

Analysis

After having presented results for each study site, now I will put this data together to build relationships and to compare the three Harvestline machines. To start the analysis Table 7 shows a summary of all of the results presented above.

Table 7: Summary table.

	Mosgiel	**Rotorua**	**Opotiki**
Machine used	Sumitomo SH460 HD	Doosan DX380 LC	Komatsu PC400 LC
Average extraction distance (m)	105	96	181
Cycle time	1.35 min	1.4 min	2.45 min
Piece size (t)	2.0	1.9	2.3
Productivity (t/PMH)	86	77	58
Carriage out velocity (m/s)	4.0	3.8	4.0
Carriage in velocity (m/s)	3.8	3.0	2.8

As shown on Table 7, three different machines were used at the three locations. Machine used in Mosgiel was a 46t excavator, machine used in Rotorua was 38t with a longer track and the machine used in Opotiki was 40t with a longer track. Different weights of the base machine determine the stability of it or at least give the operators some peace of mind knowing they are well stabilised on the ground. This is especially important with the mast of the Harvestline, pulling 4-6 tonnes up a slope. However, it is important to note that a heavier machine does not mean less ability to move around. This was seen in Mosgiel, where the operator would move left and right of the extracting corridor to extract stems. Considering the lower weight of the Doosan used in Rotorua, I expect the longer tracks have great effect in providing increased stability by distributing the weight more. Hence having a similar effect to having a machine with a heavier base.

Lowest average extraction distance was measured in Rotorua (96 metres) where the crew was employed to “clean up” the remaining edges of a prior harvested area. At a smaller distance the Harvestline was able to effectively extract these stems. Average extraction distance in Mosgiel was 105 metres and the Harvestline had few issues extracting stems at this distance. Only issue arising from some loss in deflection due to the location of Harvestline and pulling over broken terrain. This was easily remedied my adding a little bit of power to the pull. Longest extraction distance was recorded in Opotiki (181 metres), where the tailhold was nearly 450 metres away. The mainline within the winch system has 1000 meters of rope and this crew was right at the limit of it (mainline runs through the tailhold block and back to the carriage. So, 1000/2). Average extraction distance for Opotiki would have been even higher if not for a patch of natives beyond 200 meters preventing the operator pulling stems over the natives. These three studies were really good due to the varying extracting distances. Hence outlining that the Harvestline has no issue extracting stems from 10 meters to 400 – 450 meters.

Even though extracting a stem at any of these distances can be done, the time taken for the machine to extract stems increases with increasing distance. This has a detrimental effect on the productivity and cost of using the machine. Looking at the data presented, the longest average cycle time was recorded in Opotiki, which we would expect to be the highest due to the increased extraction lengths and some other factors discussed soon. The next longest cycle time was recorded in Rotorua. This does not fit the relationship due to Rotorua having a shorter extraction distance than Mosgiel. This average cycle time could have resulted from error in recording time, operator taking longer, stems being harder to spot due to slash, or stems getting caught on rocky slopes. Lastly, the shortest cycle time was recorded in Mosgiel. Although having a longer extraction distance than Rotorua. This shorter cycle time in Mosgiel could have resulted from an error in recording time. This was apparent when analysing the cycles using the GPS data. This analysis was done by following along each GPS waypoint and I could see that in some instances the operator spent less than 3 seconds to unhook and was also extremely quick to hook on to a log.

The Harvestline is capable of extracting stems out to great lengths but as mentioned above it comes at a cost to cycle time. This higher cycle time at a greater length can cause the productivity of the machine to fall. Highest productivity was recorded in Mosgiel and this could have been a result of shorter cycle times and 2.0 tonne average piece size. Rotorua had a lower productivity due to having smaller stems (1.9 tonne). This could have been a result of the deployment of the crew too. As I mentioned earlier this crew was cleaning up the gullies, this meant pulling up stems as well as substantial amounts of slash and broken stems from the gullies. Hence, some extraction cycles did not carry stems that could be turned into logs. It is important to note even with a lower productivity, the operator and his machine carried out its tasking, which was to clean up the gullies. Lastly the productivity in Opotiki was 58 t/PMH. Even though this site had the biggest piece size (2.3 tonne) the longer extraction time and extraction distance caused the productivity to drop.

Looking at the carriage velocities, there is a distinct difference between the speed of the carriage going out and the carriage coming in. This difference is more pronounced in Rotorua and Opotiki as opposed to the smaller difference in Mosgiel. It was evident in the Mosgiel study that the operator would release the carriage at the top of the extraction corridor almost in a shotgun fashion. This was seen in the Rotorua study too. Looking at the velocity of the carriage going out in Opotiki (4.0 m/s), it is the same as Mosgiel and more than that of Rotorua (3.8 m/s). This shows that there was no decrease in speed even when the main line was pulled out to 450 meters. Looking at the carriage in speeds, they are less than that of the carriage going out. This is to be expected due to the carriage coming in loaded. In Mosgiel the carriage in speed was only 0.2 m/s less than that of the carriage going out. This demonstrates that the Harvestline had no issue extracting these stems. The slowest carriage in speed was recorded in Opotiki and this was due to the operator slowing down the carriage to prevent branches of the stem being extracted, bringing the mainline and the haul back line together, making the cables rub and damage to the cables. Especially true in Opotiki where there was such huge deflection in cables due to the tailhold being further away.

Cycle times recorded for each site is shown above in the results section under the relevant site name. Figure 38 shows an accumulation of all these cycle times across the three study sites.

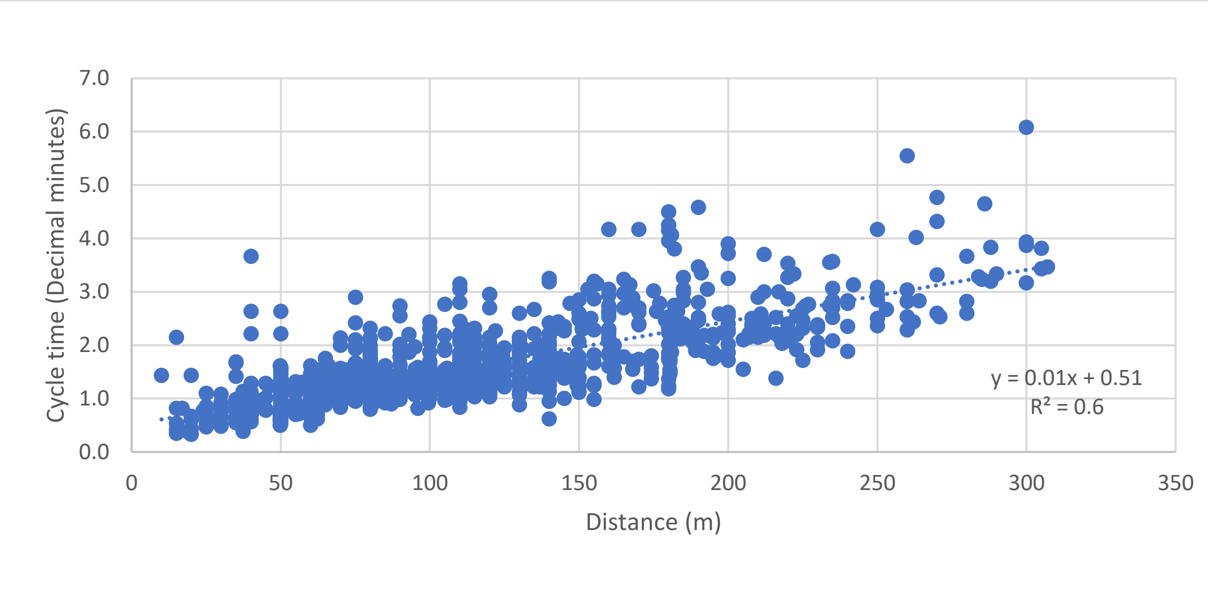

Figure 38: Cycle times Vs the extraction distances of the entire study.

Looking at Figure 38, we can see that the most common extraction distance recorded within this study was under 150 – 170 metres. However, some extractions were carried out even out to 300 meters. This overall relationship between cycle time and extraction distance is represented by:

$$Cycle\ time = 0.51 + 0.001\ \times Ext\ dist.$$

Figure 39 below shows the productivity per cycle and the average extraction distance for the entire study.

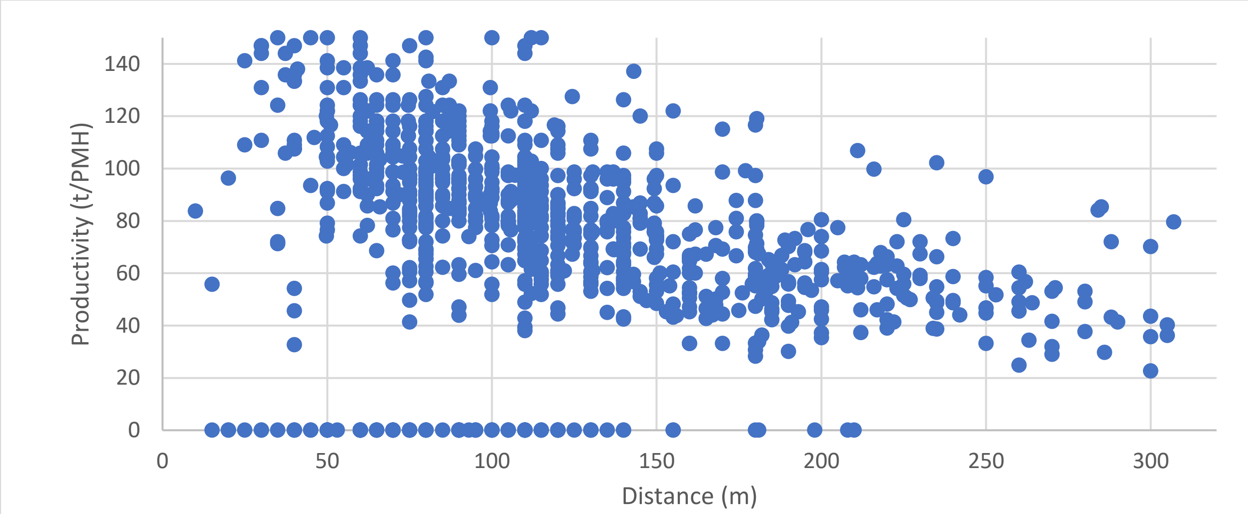

Figure 39: Relationship between distance and productivity.

Looking at Figure 39, there is a lot of fluctuation in productivity at the middle of the extraction corridor and this could have resulted from the fluctuations in cycle times as I discussed earlier. Productivity values of 0 t/PMH are from Rotorua, where the operator sent out the carriage and extracted slash and tops that could not be turned into logs.

To accompany this data, I have carried out a multiple regression analysis to see the effect on cycle time, with changing distances, number of stems being carried and the payload carried. According to this analysis distance and payload affected the cycle time. However, the number of stems extracted had no significant effect. This relationship is shown by

$$Cycle\ time = 26 + 2.9 \times Payload + 0.6 \times Ext\ dist.$$

Table 8 shows each study site within this study compared to studies around the world involving bigger yarders and custom-made excavator-based yarders. These results are compared by considering carriage configuration, average line length, piece size, productivity, type of operation, country and number of cycles recorded.

Table 8: Comparing the three study sites to other yarder studies.

Yarder Type	Carriage Type	Line Length m	Piece t	Productivity t/PMH	Operation Type	Origin	Cycles n
Sumitomo SH460 HD Harvestline	Mechanised Grapple	105	2.0	86	Clearcut	Mosgiel, NZ	353
Doosan DX380 LC Harvestline	Mechanised Grapple	96	1.9	77	Clearcut	Rotorua, NZ	431
Komatsu PC 400 LC Harvestline	Mechanised Grapple	181	2.3	58	Clearcut	Opotiki, NZ	246
Alpine MDWS	Grapple	103	0.5	63	Clearcut	Malaysia	54,624
Madill 124	Grapple	100	0.8	58	Clearcut	Australia	184
Thunderbird 6355	Grapple	160	0.9	86	Clearcut	New Zealand	123
Thunderbird 255	Slings	233	1.5	39	Clearcut	New Zealand	165
Madill 122	Slings	267	0.7	44	Clearcut	USA	70
Timbco T425	Slings	80	0.6	15	Thinning	USA	218
CAT 315 L	Slings	80	1.4	30	Thinning	USA	237
Doosan DX 210W	Slings	120	0.3	11	Clearcut	Norway	149
Modified JCB	Slings	130	0.4	17	Clearcut	Ireland	90

The first three rows of table 8 represent the three machines studied and the following rows show studies done around the world. All of these studies are referenced in the references section. As shown in Table 8, the extraction lengths of the three Harvestline studies were average compared to other studies but the average piece size was bigger compared to other studies. However, the productivity of the three studies done are higher than other studies. This could have been a result of faster cycle times and medium extraction distances.

Discussion

All three machines studied were employed to do different tasks, such as shorter/medium distance extraction, cleaning up gullies and longer distance extraction. It was observed that the Harvestline was extremely capable of extracting stems out to 290 m, extracting very large stems and working in a variety of settings. The analysis of the data gathered showed that the Harvestline is productive out to 250 m which is the extreme extraction distance for this study. Comparing the Harvestline to yarders around the world (Table 17) showed that the machine was as capable, if not more capable that well known yarding systems such as Madill and Thunderbird. For me the Harvestline stood out from other systems due to the work I observed it doing, how easy it was on the operator and the fact that all of the contractors studied were meeting or exceeding their daily tonnage requirements.

Looking at some of the advantages offered by the Harvestline, the first is the absence of guy lines. Not having guy lines allowed the operators to swing left/right of the yarding corridor or to move the Harvestline to the left/right of the yarding corridor to pick up stems. This reduced the number of tail hold shifts. This affected the operation significantly in Mosgiel where the operator in charge of moving the tailhold was also operating the skidder. Having fewer tail shifts meant that the skidder operator could keep moving stems up the landing and hence keep the “production line” going. Additionally, the operation would be cheaper due to not having a designated tail hold machine operator. Another benefit of not having guy lines is that other machines can work extremely close to the Harvestline. This was seen in at all three study sites where grapple excavators were working extremely close to the Harvestline. Having a machine close by, Harvestline operators did not have to worry about bunching the logs nicely. This decreased the time taken to unhook and decreased the overall cycle time. Another benefit of not having guy lines meant the Harvestline could work on landings such as in Opotiki (Figure 18). This is extremely advantageous when working in smaller, confined woodlots.

Another beneficial feature of the Harvestline is the cabin layout. This was observed in Opotiki, where the Harvestline had a custom-built rear entry cab. The view from the operators’ seat was excellent, where he could monitor the screens, keep an eye on the stem being pulled in and keep an eye on the winches. Custom cab was also complete with all the creature comforts and had safety latches on all of the windows that could be accessed in a hurry. Another “nice” feature is the built-in tension monitor. When picking up a stem and transporting stem, it allows operators to see the weight applied on the cables and to drop the stem if gets too heavy.

Figure 40: Operators view from the cab

Overall size of the machine and the reliability were other beneficial features. Due to being excavator-based, Harvestlines are not very big machines (relatively). Being considerably smaller allowed the machine to get up difficult landing such as Opotiki (Figure 18) and caused considerably less soil disturbance when moving from one setting to another. According to the crews, the Harvestlines were extremely reliable if maintained properly. Another beneficial feature observed during the relocation of the Harvestline was the grapple attachment. In Rotorua, the grapple on the Harvestline picked up and moved the Hawkeye grapple system from setting 1 to setting 2 (Figure 41).

Figure 41: Harvestline carrying the Hawkeye grapple.

The Hawkeye grapple system is another attachment that is extremely beneficial. Talking to crews, they mentioned how the grapple system is rarely broken-down and crews from Rotorua and Opotiki mentioned how EMS Rotorua is always on hand to fix any problem that arise. That could be over the phone instructions or a site visit. During the study I saw the Hawkeye grapple system extracting stems that were 6-7 tonnes with ease. This is as a result of a diesel engine powering the hydraulic scissor arms, allowing the operator to get a good grip on the stem. Another key feature on the Hawkeye grapple system is the three night and day cameras. These cameras face front, down and back covering a vast area which helps when extracting at long distances. According to the crews the night feature on the cameras is very important because of early morning starts in forestry.

Figure 42: Hawkeye grapple system.

Finally, the most important advantage is how easy it is to use the Harvestline. There is a button on the joystick to pick whether the carriage is going out or coming back in. The Joystick is used to move the grapple arms, there is one button to tighten the grip and one to loosen it. There are two pedals on the floor, one of the sending the carriage out or bringing it in depending on the option chosen by the operator (button on joystick). The second pedal moves the carriage up and down. Essentially making the operation super easy and efficient.

The Harvestline is a very capable machine that is ideally suited for tight landings, smaller woodlots and forests with yarding corridors of around 250 metres or less. It is a reliable, easy to use system that is very productive if used in right conditions. It comes with the Hawkeye grapple system which is as reliable as the Harvestline with the ability of lifting 6 – 7 tonne stems.

Conclusion

This study showed the Harvestline working in commercial forest carrying out the entire extraction, in a clean-up capacity working in conjunction with other extracting systems and working in smaller and restricted woodlots. All of the operators working in these sites managed to meet or exceed tonnage requirements and fulfil company demands.

Some observations made were the fast cycle times and a resulting higher productivity per productive machine hour. The machine was successful due to its lack of guy lines allowing it to move left and right to expand the extraction corridor. Not having guy lines also allowed a grapple excavator to work extremely close to the machine, was important in Opotiki due to limited room on the landing. The smaller size of the Harvestline also meant that it was easier to bring on site and making it better suited for challenging sites.

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Appendix

Day________________________

	Timing					Parameters				Comment
#	C-OUT	CHOK	C-IN	UNHO	DEL	DIST	LAT-D	STEMS	TOPS	
213	38	21	31	2		190		1		
214	38	20	34	3		125		1	1	
215	33	83	41	3		135		1		Dropped log half way, pinch
216	34	79	39	4		130		1		
217	34	26	35	3		140		1		
218	34	23	27	3		140		1		
219	36	18	33	4		145		1		
220	36	35	64	6	21'	145		1	1	Adjust tower
221	33	31	32	3		150		1		
222	35	22	39	4		155		1		
223	32	22	51	4		160		1		
224	33	52	71	6		170		1		
225	37	19	43	5		180		1		
226	39	47	40	5		185		1		
227	43	56	151	5	30'	180		1		Dropped 1/10 n out Pete coming up machine
228	52	23	53	4		195		1		Broke stem half way @ line
229	46	21	55		137'	190		1		shifting tailhold
230	14	13	21	6		60		1		
231	19	30	24			80				

Figure 43: Example data entry sheet

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