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Forestry 4.0 for Improving Yarder Design and Operations:

A Valentini Yarder Case Study

Forest Engineering Honours Project

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Executive Summary

With the rapid advancement in technologies, like many other industries, Forestry is entering the 4th industrial revolution. The goal of Forestry 4.0 is to interconnect the timber production chain from harvest to final product. There are four key steps to developing Forestry 4.0: (1) establishing the real environment (2) creating the 'Internet of Things', (3) developing current technologies around atomisation, and (4) developing the technology to predict and take corrective action of live data.

This report focuses on the connection of machine to manufacturer and uses passive data processing of a live data feed to highlight opportunities for real-time yarder management. The study used information from a Valentini V-600 that was set up with 'Forestry 4.0', being a live-stream of data from the working yarder to the manufacturer server that could be retrieved via the internet. While the database contains a contentious stream of data for 44 yarder parameters, a selection of 3 parameters was made to illustrate the potential efficacy; being carriage position, RPM and fuel status.

The results show that the data is useful not for not only the yarder manufacturer, but also the owner and forestry company. Example results include being able to develop a realistic relationship between extraction distance and cycle time using the carriage position data alone – so the area they were working Cycle Time = 3.93 + 0.0013 x Extract Distance. This shows the possibility's of real time productivity statistic in the future, without the need to complete a time and money consuming productivity study.

With carriage movement information, as well as engine start and stop time, the project also showed that Scheduled Machine Hours (SMH) and Productive Machine Hours (PMH), can be deducted. Fuel use can also be tracked over working time. Such data can be useful statistics for costing, life expectancy and depreciation.

Another example was the workload of the yarder as per the RPM. The data can be used to establish the 'normal' settings for the yarder. For the example results the yarder operated with 800–850 RPM when idle and between 1950–2000 RPM when accelerating from a stationary position just after loading or unloading. This allows future auto-corrective actions when the RPM values go outside these ranges in these specific actions.

This report has showed how a live-stream of data from an operational yarder can be used. This project had to use an Italian yarder as such data is not yet available in New Zealand. One challenge for implementation here in New Zealand will be the lack of live data readily available.

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Introduction

Industrial work around the world is becoming more advanced by the day. With advancements in all areas of technology, especially the development of the internet of things and services the 4th industrial revolution is well underway. It is more commonly known as 'Industry 4.0'. The goal is to interconnect resources, information, objects and human beings in industrial value creation (Kagermann, Wahlster, & Helbig, 2013). The connections made by Industry 4.0 will increase production, reduce costs and increase safety.

Forests and trees are extremely diverse, with no two being the same, so the process of harvesting these forests and trees is always different. This can mean that different trees or different processes in the harvesting chain can produce different challenges. However, the introduction and use of Industry 4.0 In the forestry sector could help adapt to these problems or minimise their effect. It could also increase safety, production, profit and more. Industry 4.0 in the forestry sector is known as Forestry 4.0.

Forestry 4.0 is a big step for New Zealand and will take time to implement. The important steps that need to be made are understanding where and how it can be implemented across the supply chain. Most modern machines have got the ability to produce a live feed of their data to anywhere with internet access around the world. It is important that this data is interpreted correctly so a beneficial outcome can be achieved.

Literature Review

What is Forestry 4.0 and where is it being used

Forestry 4.0 is the implementation of the 4th industrial revolution (Industry 4.0) in a forestry scenario. The goal of Industry 4.0 is to achieve a higher level of operational efficiency and productivity, as well as a higher level of automatization (Thames & Schaefer, 2016). Although there are many digital technologies available on the market, relatively few people are dedicated to applying these technologies in the forest domain. Although as global industries are advancing towards the adoption of the Industry 4.0, forestry is following the global supply chain. Forestry 4.0 is broken down into 4 areas:

1) Establishing real environment, through LiDAR and drone technologies to create cyber physical production systems that can share information constantly.
2) Creating the internet of forest by having communication links between vehicle to vehicle, machine to machine, vehicle/machine to infrastructure, operations to cellular/internet and real time communication in remote operations.
3) Developing the current technologies around automation, sensors, machine learning, and robotics.

4) Developing technology to predict and take corrective action of live data, eg moving away from passive use of data for data monitoring and moving towards live data (Feng & Audy, 2020).

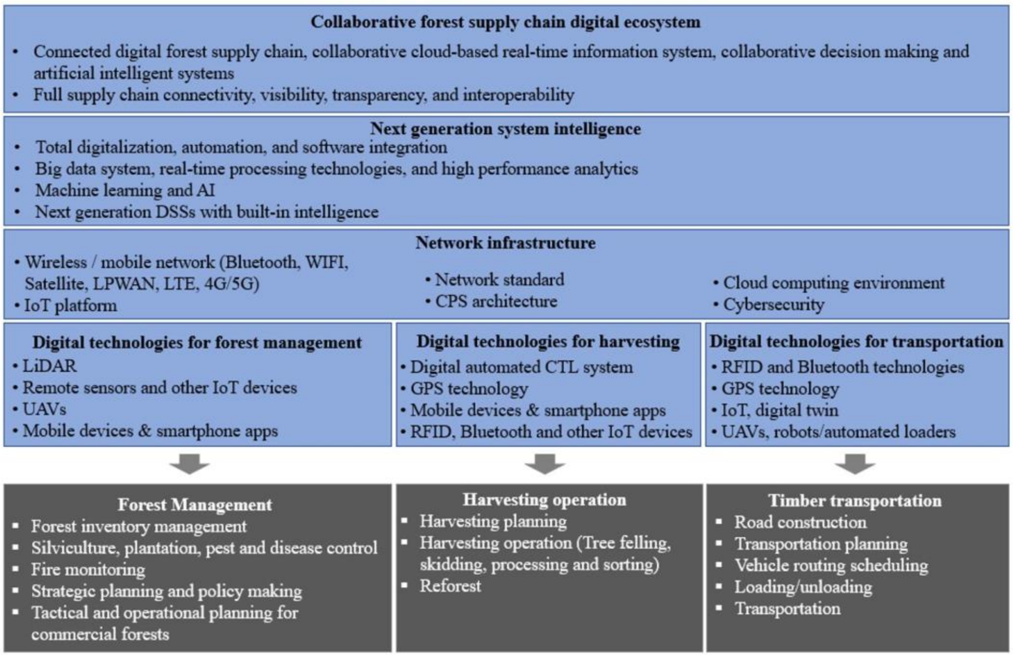

Figure 1: Forestry 4.0 conceptual framework (Feng & Audy, 2020)

The development of "cut to length" systems in Scandinavia with real time data on the onboard computers in the harvesters means that the real time data can flow from the harvesters back to the office and from the office back to the harvesters. This can be useful when new log types are needed and almost instantly, they can began being cut and produced. Forestry 4.0 is currently being used within mills to produce quality timber from low value second rate logs (Bosson, 20119). The internet of things (IOT) is the idea of the connection of all devices from cell phones to sensors to heavy machinery being connected to the internet. This would allow all to be able to talk and communicate with each other (Spark, 2021). This is an essential aspect of the development of Forestry 4.0.

Challenges with implementing Industry 4.0 in the forestry sector

For Forestry 4.0 to be successful it needs to be applied across the whole supply chain in collaboration with all parties involved. There is also going to be challenges with the implementation and it cannot happen with a "flick of a switch" due to massive amounts of data that needs to be processed constantly across the board. A lot of currently employed people in the forestry supply chain will not have the skills required to fill the new roles (Feng & Audy, 2020). The fourth industrial revolution will cause a massive disruption in labour markets, "New categories of jobs will emerge, partly or wholly displacing others. The skill sets required in both old and new occupations will change in most industries and transform how and where people work" (The future of jobs:

employment, skills and workforce strategy for the Fourth Industrial Revolution, 2016). The challenges for small and medium sized business are to create flexible organisational structures, and to improve their employee’s knowledge of the whole supply chain and all of the processes involved (Schroder, 2017). The introduction of greater and more technology must not be treated as a threat to people’s jobs but instead as an opportunity to increase their productivity and help with their decision making. From a business standpoint, it should help increase their business competitiveness and productivity (Zervoudi, 2020).

Industry 4.0 could well be delayed around the world due to Covid-19, but as New Zealand has suffered comparatively less than most countries, we have the potential, due to our economic situation to push ourselves into developing Industry 4.0 in all areas (Jamieson, 2020). With a crucial step of Industry 4.0 being the development of the IoT this brings a big challenge to the development of Forestry 4.0 in New Zealand. As seen below in Figure 2, the 3G reception for New Zealand’s most popular service provider Spark covers not even close to all forest areas shown next to it.

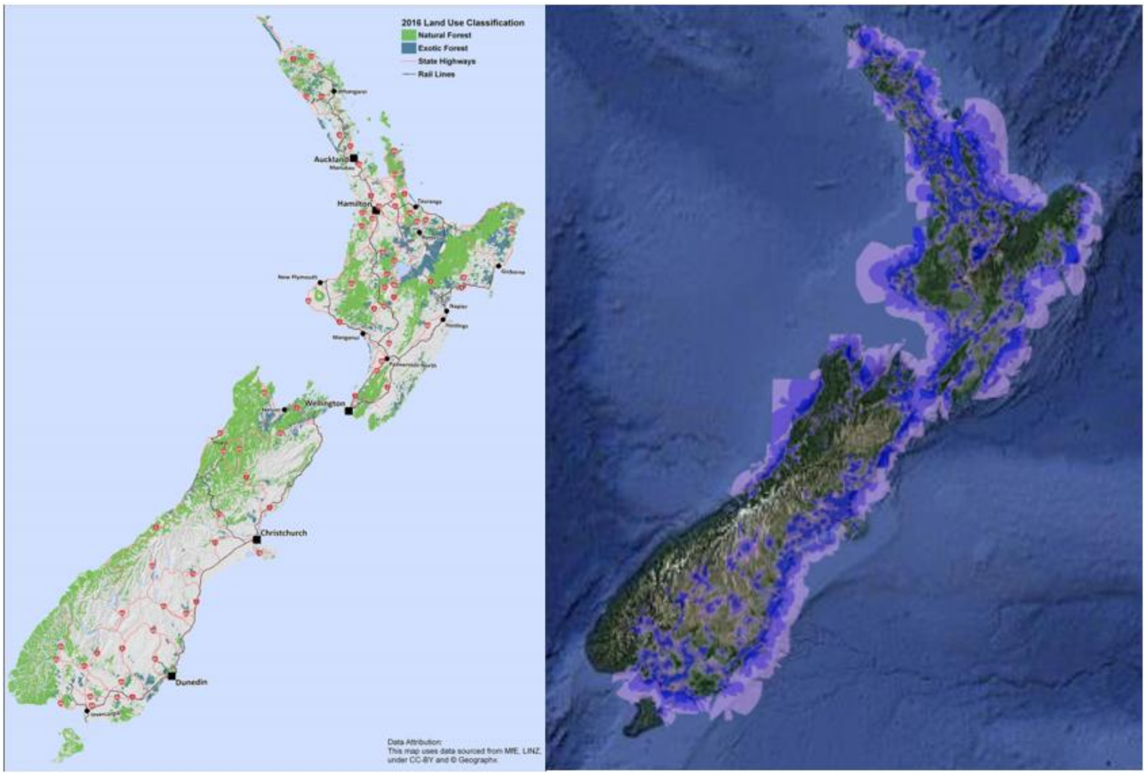

Figure 2 On the left shows a map of New Zealand’s forests (Industries, 2020), and the right shows 3G coverage provided by Spark (Spark, Spark NZ Network coverage and compatibility, 2021).

Current Data

Data collection for forest inventory using smart phones is becoming more and more popular (Scholz, 2018). However, the use of drones could make it unnecessary by having all the live feed inventory information on a smart phone. New Zealand will have the biggest 3 years of recoverable volume of radiata pine from 2022-2024, with over 45,000,000m^3 each year. The predicated values do not surpass 45,000,000 again until 2050 (Limited, 2016). This huge jump in recoverable volume will mean that harvesting crews will be under pressure by forest owners and will be working hard with minimal allowances for down time. This will also mean it could be quite difficult to bring in new machines, policies, and ways of working. However, with the increase of productivity it could be worthwhile to take the time to introduce Forestry 4.0 aspects into harvesting and the supply chain. Another factor holding back the implementation of areas of Forestry 4.0 is that fact that in the next 3 years (2022-2024) over half of the recoverable volume is owned by small scale owners (Limited, 2016). The smaller owner's volume will likely be harvested by smaller contractors, who will likely not want to front the potential large up-front capital for Forestry 4.0. It is said that the factors creating a high productivity and low cost in forest harvesting are not limited to skilled operators and efficient harvesting equipment (Parajuli, Hiesl, Smidt, & Mitchell, 2020). These are both seen with Forestry 4.0 as the equipment will be more advanced and the operators will become more skilled due to the machines creating a system where decision making is simplified. As an example of the potential impact, the Bosch Rexroth factory in Germany has reduced set up time from 450 seconds to 0, reduced inventory management from 3 to 1.5 days, cut the cycle time from 474 to 438 seconds and saved 500,000 euro a year with the introduction of Industry 4.0 (Innovation, 2019).

How can Forestry 4.0 be implemented in NZ and why it will be useful?

It is stated that for Forestry 4.0 to be fully working it can't come from one company but from a chain of all companies working on the forestry supply chain. This will increase efficiencies and reduce operating costs due to end to end digitisation of all physical assets (Feng & Audy, 2020). The implementation of digitisation makes the supply chain more efficient, agile and customer focused (Geissbauer, Lubben, Schrauf, & Pillsbury, 2018). If New Zealand is slow in implementing this compared to other countries, we have the potential to not be able to compete with other countries export prices.

In New Zealand between February 2011 and February 2021 there was a total of 52 fatalities and 1458 serious injuries that resulted in more than a week away from work in the forestry industry (Worksafe, 2021). The introduction of greater automation and computerization will increase physical safety as it makes their tasks more flexible and socially more inclusive. However, with workers being more engaged with tasks requiring decision making and management, it will expose them to greater psychological stress (Leso, Fontana, & Iavicoli, 2018). With there being no required level of education or training to work in the forest and logging industry according to New Zealand careers, there is potential for the change in work to be very difficult for some workers. This will be due to their education level not being up to it. Production Machinery Ltd (PML) is a supplier of smart factory solutions, it is a part of the Haier group which includes Fisher and Paykel in New Zealand. It is an example of a company developing in alignment of Industry 4.0 in New Zealand (Innovation, 2019). Currently in New Zealand and throughout the world there is research happening around the use of wireless sensor networks in forestry. The sensors are proposed for use in forest management, allowing the ability to monitor key variables at real time. The sensors can also be used in fire monitoring, with temperature sensors (Bayne, Damesin, & Evans, 2017).

Yarder specifications for the study

The yarder that was used in the report is the V600/M/3/1000/B10. This model of yarder has a skyline cable capacity of 1000 meters, a mainline cable capacity of 1100 meters and a haulback line cable capacity of 2000 meters. The fuel tank is 100 litres and the whole yarder, including the cables weighs 19 tonnes. The width, height and length are 2.40, 3.45 and 4.70 meters respectively.

Objectives

The aim of the report is to use the access I have been given to the live feed data of a Valentini yarder and find or see if it's possible to calculate some beneficial figures which will help all parties involved in the use of the yarder. This will mean in the future, real time adjustments and corrections can be made in response to the live data to improve the productivity, increase safety or reduce cost. The report will also aim to understand how that link and other areas of Forestry 4.0 can be implemented in New Zealand. It will detail the potential challenges and recommended future steps. Areas of successful use of Industry 4.0 will be compared to areas of potential implementation in the forestry sector in New Zealand. The challenges of this will also be discussed. The data will be exported to MS Excel for the data manipulation.

The objective for this project is to process the 44 variables of data available for download from the Proemion (https://www.proemion.com/en/products.html) portal live data feed to find beneficial information from the Valentini yarder manufacturers. From this objective, sub-objectives will be derived. Some sub-objectives being finding:

1) Minimum, maximum and averages for cycle time and extraction distances
2) The average cycles the yarder can complete on a full tank
3) The range and median of revolutions per minute
4) The areas New Zealand forestry has to improve before the data discovered for Valentini yarders and Forestry 4.0 will be readily available around New Zealand.

Methodology

Data available from Valentini

Valentini was founded in 1979 in the North of Italy, in the alpine region Trentino-Alto Adige. It was originally a mechanical and metal construction enterprise but eventually moved to the construction of mobile cable cranes (Valentini Mobile Cable Yarders, 2021). It is a family run business and now has 5 different yarders. They produce the V400, V550, V600, V850 and the V1000 model. They also have “special machines” they have made which include: V1500, V400 installed on sled, tower installed on Mooroka Caterpillar, V550 on an excavator, V600 on excavator and cable yarders on trucks with integrated loading crane (Valentini Mobile Cable Yarders, 2021). With IoT capability on board, yarders can transmit a live data feed anywhere around the world. The information that is available is as follows: Three ropes, cart status, command active, carrier, pulling, emergency stop switch, tracks, engine running, “node in mach”, “node 80 on”, Rpm sensor alarm, machine emergency, forest emergency, diesel reserve, water temperature alarm, oil pressure alarm, stop for reserve, machine active command, active commando forest, active command cable, diesel level, engine temperature, battery voltage, engine revolutions, pressure 1, pressure 2, pressure 3, traction speed, speed back, trolley position, discharge point, loading point, end of line, joystick 1, joystick 2, joystick 3, unfold the forest, pull wood, take command forest, automatic forest, blocks cart wood and free wood cart. This information is directly translated from the database, so currently some of the data available is hard to interpret without some translation. The dataset from the hauler is raw and needs interpreting. If a connection is made and the outcome is beneficial in any way to the harvesting crews’ performance, it can be translated to other haulers around the world. The proof of live feed information on a hauler being analysed and providing real time beneficial feedback is a huge step in Forestry 4.0.

Process

The 3 variables used within the study are carriage position, Diesel level and Revolutions Per Minute. These variables are exported from the Proemion portal to MS Excel where the data is processed. For each variable and desired result, the process is different and is explained below with the results.

Study timeframe

For the study, the week of the 14th of June to the 18th of June was selected as a good representative week for a sample. Firstly, it was difficult to find a week where all 5 days were fully worked. Secondly the 5 days provide variation within key variables that are used throughout the study.

Results

Carriage Position (Posizione carrello)

Analysing the exported data and graphs produced by the Proemion portal from the carriage position the following can be established: Scheduled Machine Hours (SMH), Productive Machine Hours (PMH), the Utilisation Rate, Cycle times and Extraction Distance. Below each result will be shown along with how it was produced.

SMH, PMH and the Utilisation Rate

The SMH are the number of hours a machine is scheduled to work for in an established period of time. For example, a yarder SMH will be calculated as the moment it turns on at the start of the day until the moment it is turned off at the end of the working day. The PMH are the time that the machine is being used and therefore productive. The Utilisation Rate is calculated by dividing the PMH by the SMH. To calculate this with the carriage position data, it was exported to Excel and compared with the graph produced by the Proemion portal. In Figure 3 below we can see the 14th of June carriage position for the whole day.

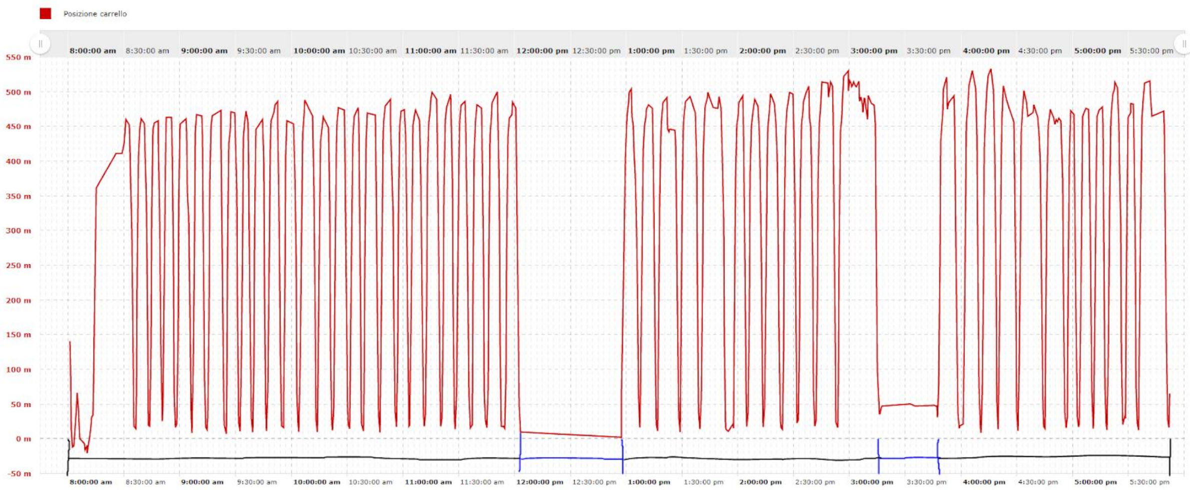

Figure 3 SMH and PMH of the 14th of June

As seen in Figure 3, the SMH is the time from the machine first being switched on to being switched off. This is highlighted by the black and blue time intervals. The PMH were calculated by subtracting the time the machine was not being used, which is the blue areas in Figure 3, from the SMH.

The Carriage position (Posizione carrello) was used to calculate the SMH and PMH. The time values used to calculate both variables were derived from the graph produced by the Proemion portal. The

	14th	15th	16th	17th	18th	Total	Units
SMH	8:59:38	9:40:25	7:50:08	6:43:33	9:51:16	43:05:00	hh:mm:ss
PMH	7:00:38	8:54:38	6:17:14	5:42:31	8:50:56	36:45:57	hh:mm:ss
Stoppage	1:59:00	0:45:47	1:32:54	1:01:02	1:00:20	6:19:03	hh:mm:ss
utilisation	78%	92%	80%	85%	90%	85%	-

SMH, productive machine hours and utilisation rate were calculated for every day in the week of the 14-18th of June 2021. Below in Table 1 this data is displayed.

This information can be helpful for multipe groups of people. Firstly, the manager of the harvesting crew to see if they are completing the hours they are contracted to do. Secondly the Valentini manufactures, as it can generate an expected working life for the yarder using averages of all PMH of other yarders of the same design. Finally, it could both benefit the buyer and seller of the yarder, as it could help develop a measurable insurance value. E.g all repairs with in reason are covered by the manufacturer up to 2000 PMH.

Extraction Distance

The extraction distance of a yarder is how far the log/tree is pulled from the cutover to the landing. To find this using the carriage position data, the data was exported to Excel. Once in Excel the data was compared to the graph provided by the Proemion portal, this highlighted the data that could be considered irrelevant in further manipulation. Below we can see the Carriage position for the 14th of June.

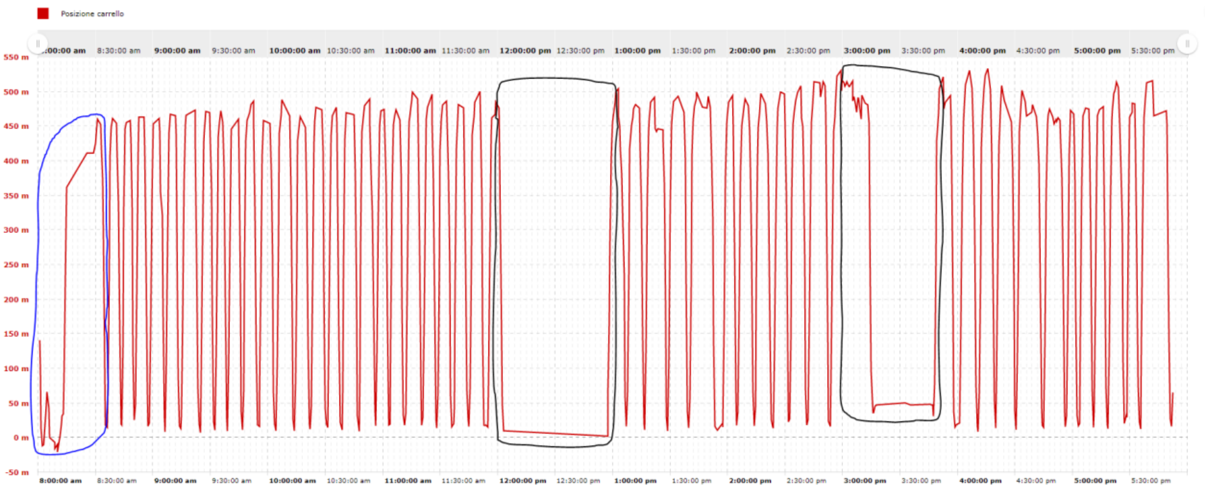

Figure 4: Carriage position on the 14th of June with breaks circled in black and discardable data circled in blue

As seen in Figure 4 above the data circled was discarded for extraction distance calculations. The data circled in blue at the start of the day is removed for simplicity and the data circled in black is removed as this is where the crew working with this yarder is having a break. Although the data discarded won't affect the extraction distance results it will affect other results that use this same dataset. From this data the furthest distance in each respective cycle was calculated using the max function in Excel. It is assumed that this results in the extraction distance as there is often many recordings of carriage position in the approximate area where the logs/trees would be hooked on to the carriage. Once the method of establishing the extraction distance was complete the data was exported for the rest of the 14th – 18th June week, and once in Excel it went through the same process.

The extraction distances from the 14th – 18th of June was calculated as were the daily average, minimum and maximum extraction distances. The results are displayed below in Table 2.

Table 2:Extraction distances for the week of June

Extraction Distances	14th	15th	16th	17th	18th	Total	Units
Average	486.2	468.4	519.1	556.5	440.1	486.3	Meters
Minimum	449	420	485	513	305	305	Meters
Maximum	535	609	570	601	623	623	Meters

The table shows a variation of 318 meters throughout the week with a maximum of 623 meters and minimum of 305 meters. These extractions distance results are important to compare with cycle time results.

Cycle times

The Cycle time for a yarder is the time it takes to complete one full cycle of the carriage from the landing out to the cutover and back to the landing. The time includes the time it takes to hook the trees in the cutover and unhooking them on the landing. To find the cycle time for each respective cycle, a clear start and stop was established. The start/stop time was decided as the lowest value in each respective unloading of logs/trees. This was found using the min function in Excel. The times were then subtracted by the previous times, as shown in the following equation Time(n) - Time(n-1). This produced a cycle time in minutes which could be linked with the respective extraction distance which was calculated above. Once the method of establishing the cycle was complete, the data was exported for the rest of the 14th – 18th June week, and once in Excel it went through the same process.

The cycle times for the week of the 14th – 18th of June was calculated as were the daily average, maximum and minimum times were calculated. These times are normally generated through on-site time studies, so to be able to create a key element of a productivity study from distance is new. Below in Table 3 are the cycle times.

Table 3: Cycle times for the week of June

	14th	15th	16th	17th	18th	Total	Units
Number of Cycles	45	50	38	32	56	221	-
Average	9.35	10.86	10.13	11.37	9.67	10.03	Decimal Minutes
Minimum	6.38	4.35	5.1	7.22	4.88	4.35	Decimal Minutes
Maximum	15.85	17.82	21.5	21.47	18.62	21.47	Decimal Minutes

This table shows the average cycle time across 221 cycles to be 10.03 decimal minutes, but with a huge range of cycle times being 17.12 decimal minutes. This shows a great variation which could be explained by a number of things like breakdowns, payload size amongst others.

Extraction distance and Cycle time relationship

Using the cycle times with the respective extraction distances, a relationship can be formed. Below are each of the 5 days extraction distance and cycle times graphed.

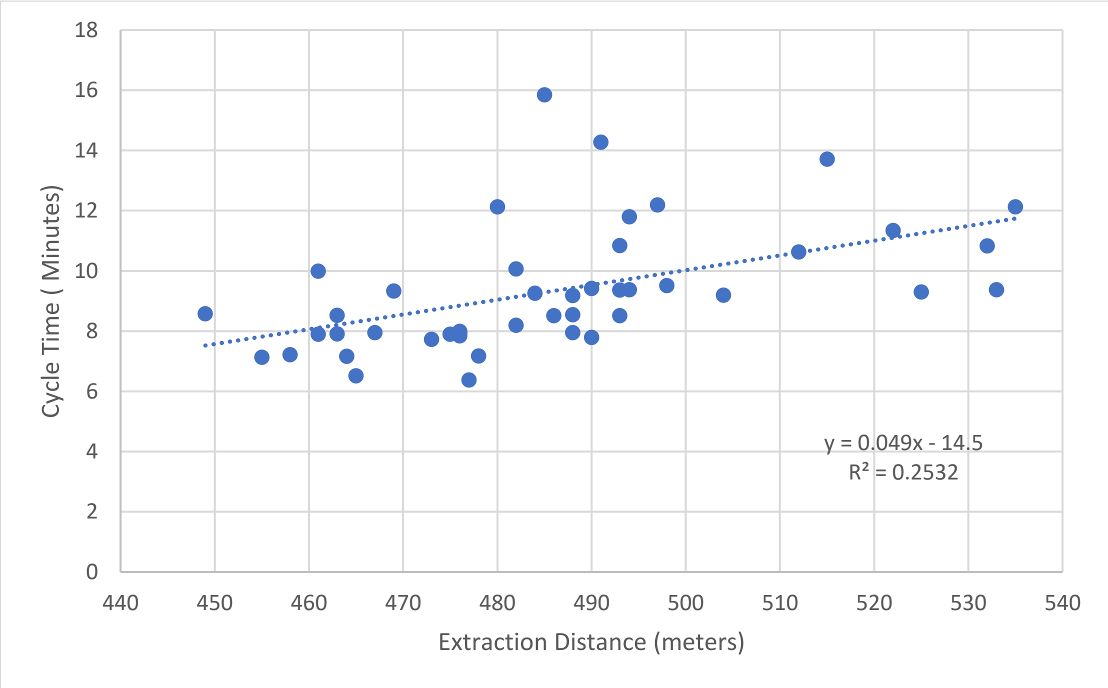

Figure 5: Cycle time and extraction distance relationship for the 14th of June

Figure 5 shows that the calculated relationship for the 14th of June is Cycle time = -14.5 + 0.05 x Extraction distance. The relationship has an R squared value of 0.2532 which means 25.32% of the variation of the cycle time can be explained by the extraction distance

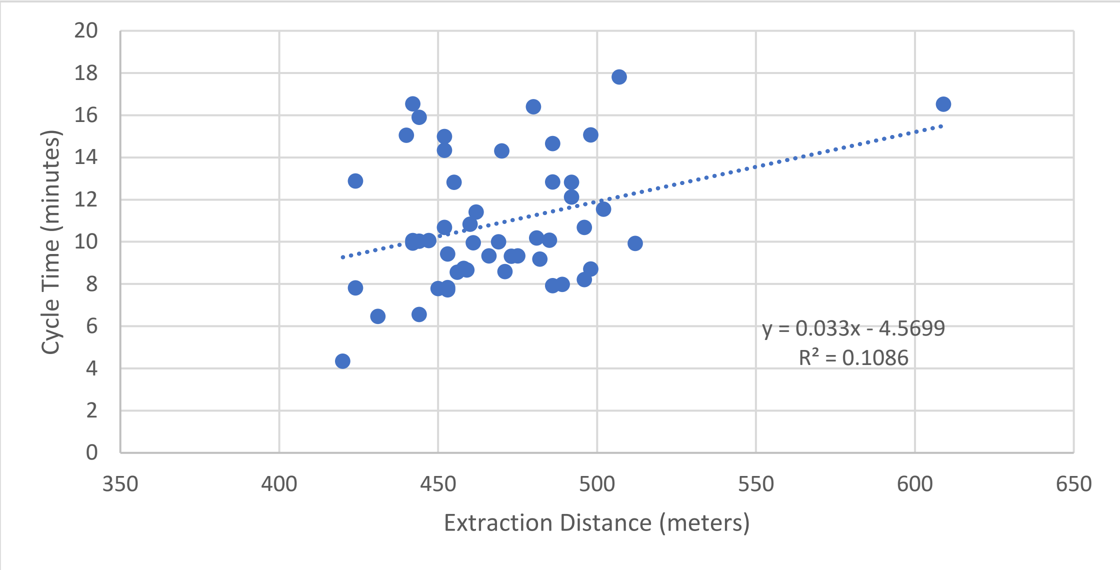

Figure 6: Cycle time and extraction distance relationship for the 15th of June

Figure 6 shows the calculated relationship between the extraction distance and cycle time. This being cycle time = -4.57 + 0.03 x Extraction distance. The relationship between the 2 variables has an R squared value of 0.1086, meaning that 10.86% of the variation of the cycle time can be explained by the extraction distance.

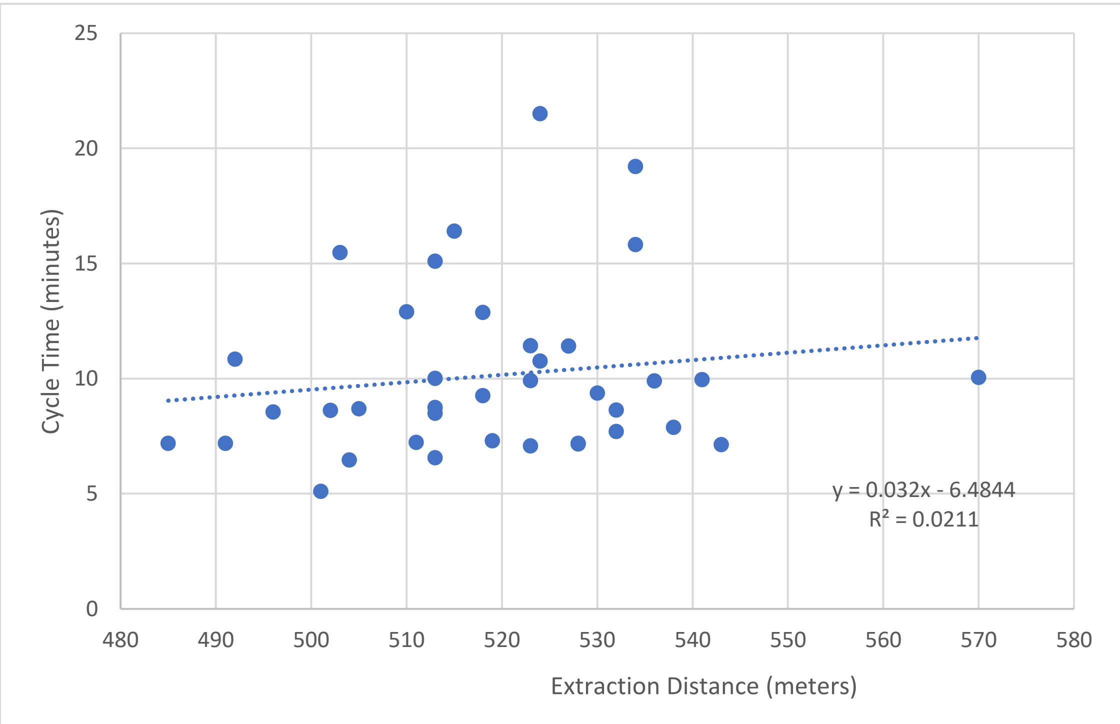

Figure 7: Cycle time and extraction distance relationship for the 16th of June

Figure 7 shows the calculated relationship between the extraction distance and cycle time. The relationship is as follows, Cycle time = -6.48 + 0.03 x Extraction distance. The R squared value for the relationship is 0.0211 which means that 2.11% of variation in cycle times can be explained by the extraction distance.

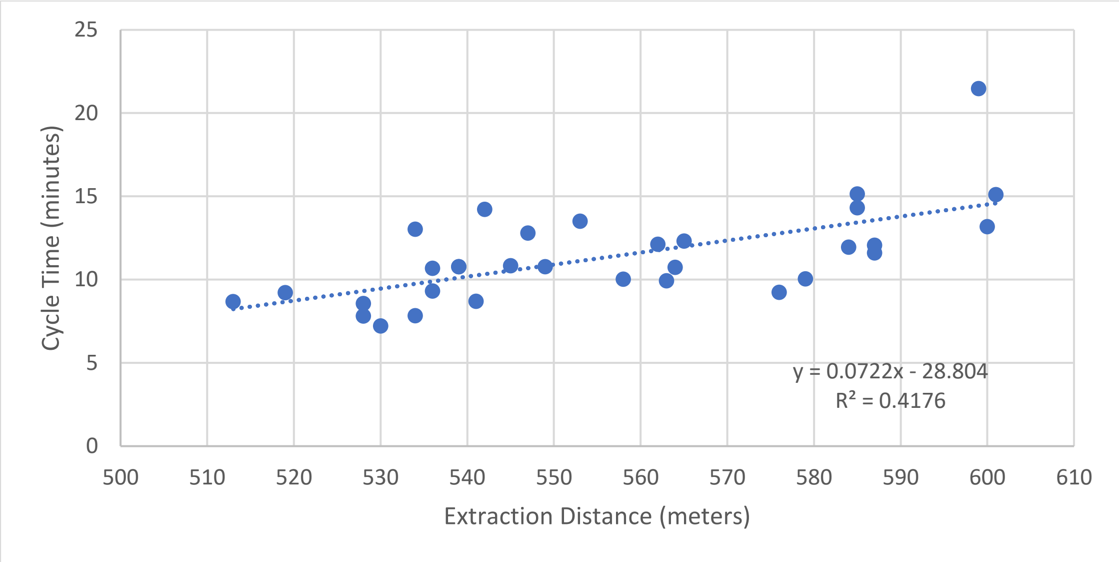

Figure 8: Cycle time and extraction distance relationship for the 17th of June

Figure 8 shows the relationship between extraction distance and cycle time for the 17th of June. The relationship calculated was Cycle time = -28.8 + 0.072 x Extraction Distance. The R squared value for the relationship = 0.4176. This means that 41.76 % of variation within the cycle time is explained by the extraction distance.

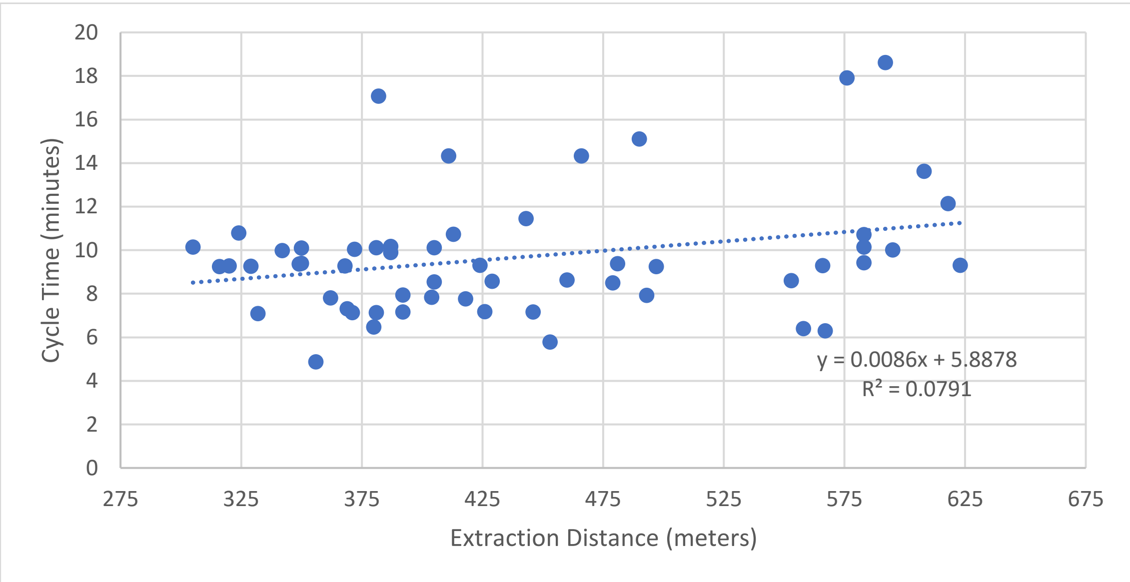

Figure 9: Cycle time and extraction distance relationship for the 18th of June

Figure 9 shows the relationship on the 18th of June to be Cycle time = 5.89 + 0.0086 x Extraction Distance. The R squared value for the relationship is 0.0791. Which means 7.91% of variation in the Cycle time can be explained by the Extraction distance. The total weeks extraction distances and correlating cycle time were correlated into one graph below in Figure 10.

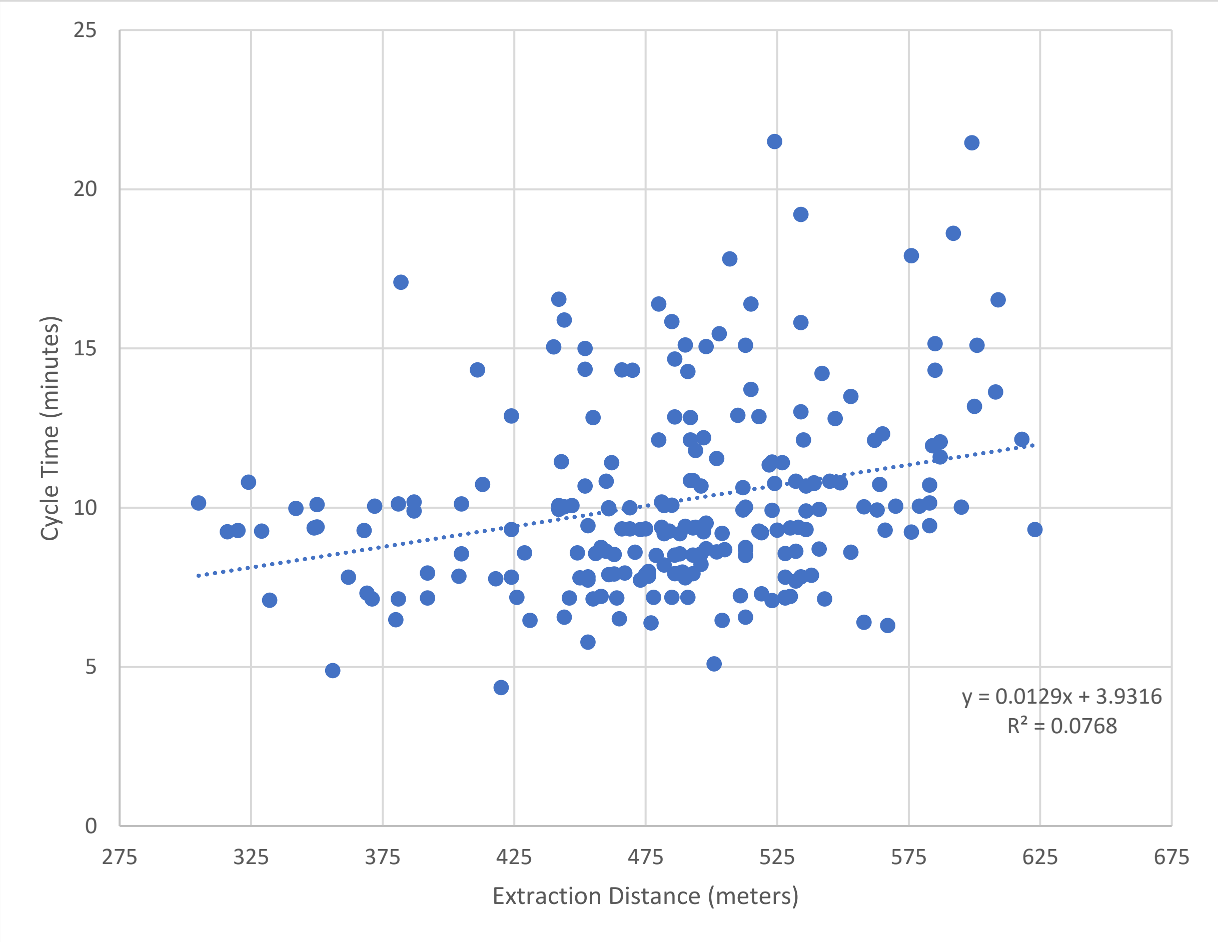

Figure 10: Cycle time and extraction distance relationship for the 14th - 18th of June

Figure 10 shows the overall relationship of all 5 days combined. In doing this, it has combined the considered bad and good days. These are days were the relationship is stronger (R squared value of 0.4176) and weaker (R squared value of 0.0211). Overall, the week of the 14th -18th of June has a calculated relationship of Cycle Time = 3.9 + 0.0013 x Extraction Distance. This relationship is plausible as when extrapolating to extraction distances closer to 0, the Cycle time remains positive. This is expected due to loading and unloading times of the logs. This is not true for some of the individual days, the 14th – 17th when extrapolated towards 0 have a negative Cycle time. This cannot be possible and comes down to the sample size of data entries. Deriving from this relationship, we can assume that the load and unload time of the logs is equal to 3.9316 minutes. This would be accurate if there were no stoppages during all the cycles.

Diesel level (Livello diesel)

Using the diesel level recorded from the yarder the data was exported and the daily fuel use along with the litres per productive machine hour can be calculated.

Fuel use

The amount of fuel being used was calculated by exporting the diesel level data to Excel. The local maximums and minimums were found by scanning through the data. With these data points, the fuel use for an established time can be calculated by the sum of the local maximums subtracted by the following local minimum. In Figure 11 below, we can see the local maximums and minimums of the 14th of June being displayed by the Proemion portal.

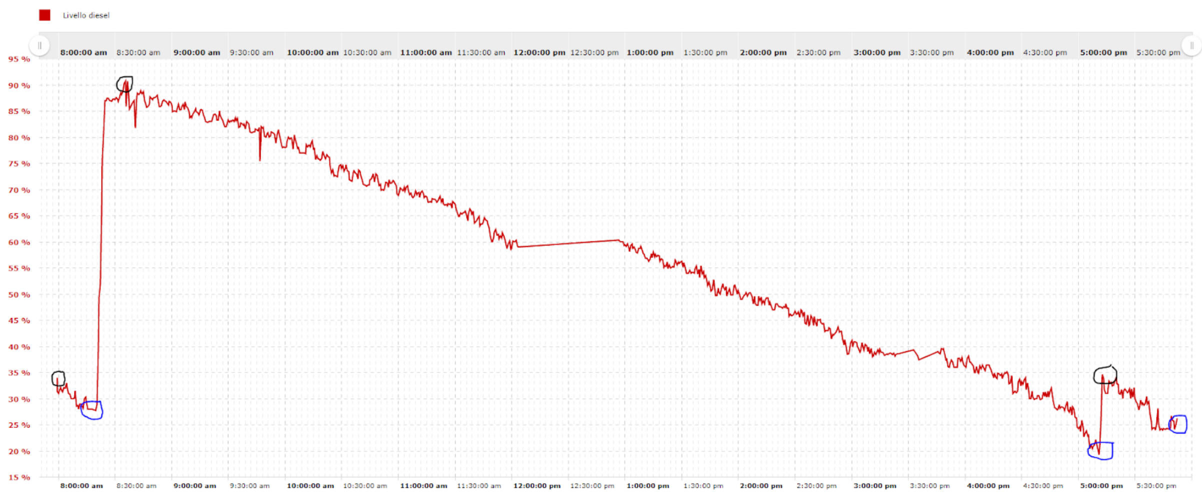

Figure 11 shows the local maximums and minimums of the diesel level on the 14th of June

In Figure 11, the local minimums can be seen circled in blue and the local maximums highlighted in black.

The fuel used for each day in the week of the 14th – 18th of June are displayed below in table 4. The values in the table are displayed as fuel used for the whole day and the fuel used per productive machine hour.

Table 4: Fuel use each day through the week of June

	14th	15th	16th	17th	18th	Average
Fuel Used (L)	62.7	83	59.9	52.7	78	67.26
Fuel use (L/PMH)	8.94	9.31	8.22	9.23	8.81	8.9

The yarders used a maximum of 83 litres of the fuel tank and a minimum of 53 litres of the tank. During the usage of 83 litres of the fuel tank the yarder completed 50 cycles in 8 hours and 54 minutes. When the yarder used 53 litres of the fuel tank during a day, it completed 32 cycles in 5 hours 42 minutes. In total, the yarder used 3.36 full tanks of fuel for the week (336 litres). The yarder averaged 65.72 cycles per fuel tank. Throughout the week the yarder averaged 8.9 litres of fuel consumed per productive machine hour. Below in Table 5, the results of the fuel usage, cycle time and extraction calculations are displayed.

Table 5: Results from fuel usage, extraction distance and cycle time calculations

Average cycle time	10 min 2 sec
Average extraction distance	486.3 m
Total of extraction distances	107500 m
Extraction distance on a full tank	32000 m
Average cycles on full tank	65.72
Average fuel use per Cycle	1.5 L
Average Utilisation	85%

Table 5 shows the average extraction distance and cycle time to be 486.3 meters and 10 minutes and 2 seconds respectively. Also, of note is the total distance of 107,500 meters that the yarder pulled wood for the week. It also shows the average fuel use for one cycle to be 1.5 litres.

Revolutions Per Minute (Giri Motore)

Revolutions Per Minute

The idea with the Revolutions Per Minute (RPM) data was to find the maximum, minimum, average and most common ranges of engine RPM. This was done by exporting the data from the Proemion portal to Excel. Once there, the data that was collected that was out of the productive machine hours was discarded for calculations. Then the maximum, minimum and average functions were used to calculate their respective results.

To find the most common range of RPM, each recording was counted and recorded in bands with a range of 50 RPM. For the 14th of June this resulted in 26 bands ranging from 750 to 2050. The counting was done by first creating a matrix with the band ranges and times, then making an 'if' statement in Excel that calculated whether the corresponding time fell between the band values it would produce a value of one. If the value fell out of the range it produced a zero, then each column for each range was summed to produce the total frequency. To test if the frequency method would be accurate and therefore the time recordings were at good intervals, the data was put into the same bands again but this time with the total time the yarder spent in these areas. To do this, the time data needed to be changed from a start time to an end time, to a total time. An example of this is changing a data point from "12:45:15 – 12:45:45" to "00:00:30". Next, the singular time value was converted to decimal minutes so it could be used for multiplication, the example above goes from "00:00:30" to "0.5". Next, another matrix is filled where instead of producing a 1 if the revolution value fell in the band range it would produce the decimal minute value. This meant when the band values were summed the value is now represented with time. Finally, the decimal minute value is multiplied by its corresponding RPM value to create a new data value of revolutions. Below in Figures 12 and 13 the comparison of the frequency can be seen as can the time that the rpm recordings fall within a given range.

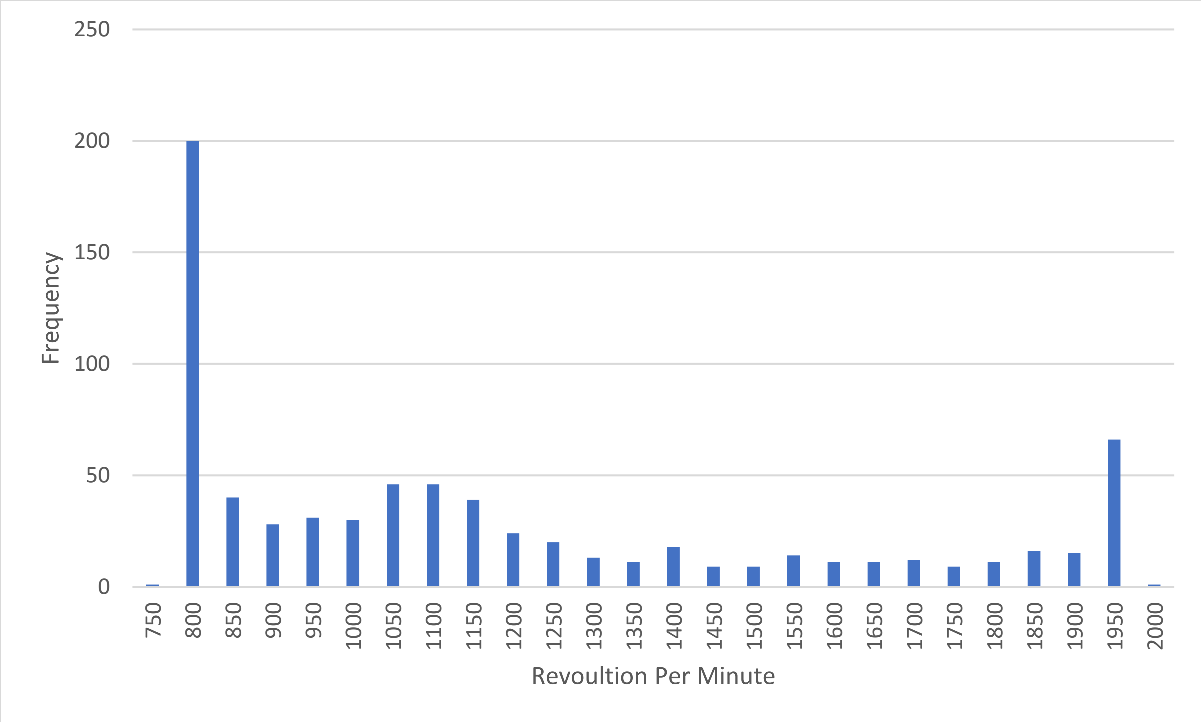

Figure 12: Frequency of rpm values

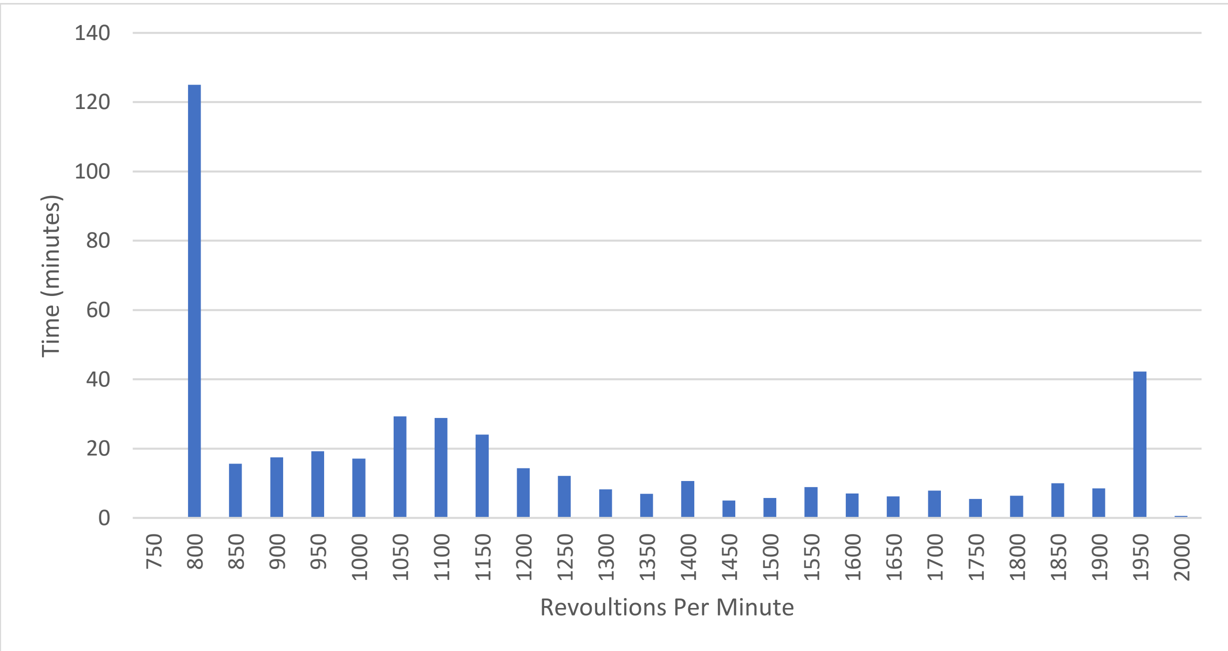

Figure 13: Total time the yarder falls within an rpm range

As seen in the Figures 12 and 13 above, the profile of the graphs are almost identical, but Figure 13 produces some valuable information so was repeated for all day calculations. The similar shape shows that the recording system is accurate for not just the revolutions per minute but also all variables that can be recorded.

The minimum, maximum and average revolutions per minute for each day in the 14th – 18th of June were calculated along with the total revolutions done within the day. All the calculated values are displayed below in table 6 along with the same quantities for the whole week.

Table 6: Results of the revolutions per minute calculations for the 14th - 18th of June

	14th	15th	16th	17th	18th	14th - 18th	Unit
Minimum	770	670	786	810	800	670	RPM
Maximum	2001	2001	2000	2000	2004	2004	RPM
Average	1211.5321	1172.477	1169.135	1203.453	1175.001	1184.8	RPM
Total	558229.68	650322.9	531383.85	438125.52	631567.13	2809629.1	Revoultions

Table 6 shows that the yarder stayed within a similar range through all 5 days. The minimum value has a range of 140 and the maximum value has a range of 4. The table also shows that the day to day average RPM value is within a range of 43 through the whole week. This is helpful as it shows that even through the variation that the yarder is exposed to in a week of a work, the revolutions per minute do not vary largely, this will be further shown below. The total revolutions completed by the yarder for the week was 2,809,629.

Revolutions Per Minute ranges

The RPM were broken down into total time spent within 50 rpm ranges. Below in Figure 14 is the total time ranges for the 14th of June.

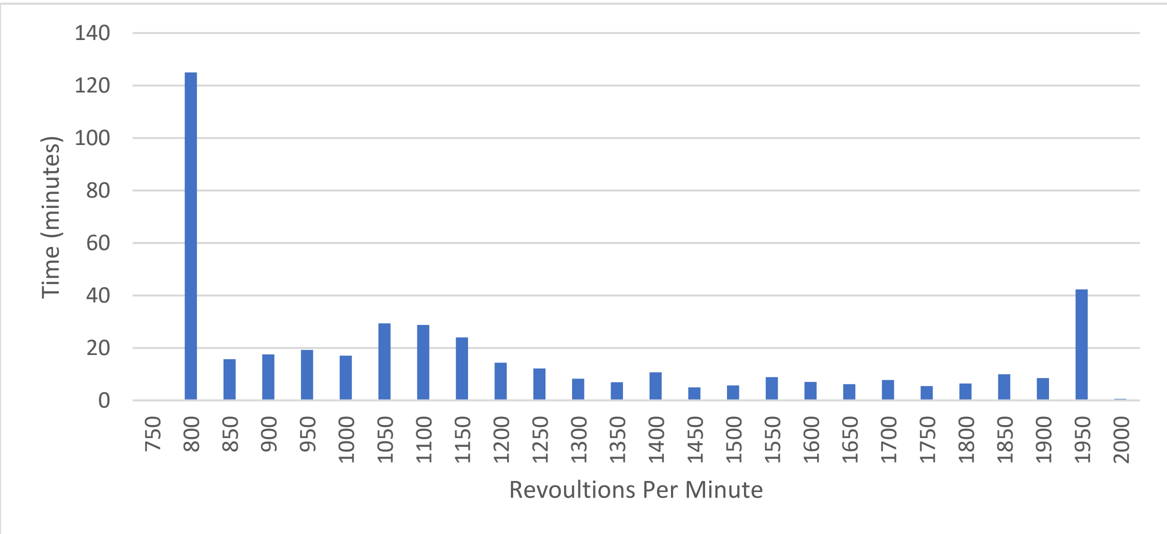

Figure 5: 14th of Junes RPM ranges

Figure 14 shows the most common range the yarder was in was between 800 and 850 RPM. The yarder spent over 2 hours within this range throughout the day. The second longest range occurrence was between 1950 – 2000 which is just below the maximum RPM value for that day at 2001. The yarder spent just over 40 minutes in this range. Below in Figure 15, the total time in ranges for the 15th of June is displayed and shows the most common range for the yarder on the 15th of June to be between 800 – 850 RPM. The total time with in this range is just under 2 hours and 40 minutes. The second most common range for the yarders revolutions per minute to be within is the 1950 – 2000 range with just under 40 minutes.

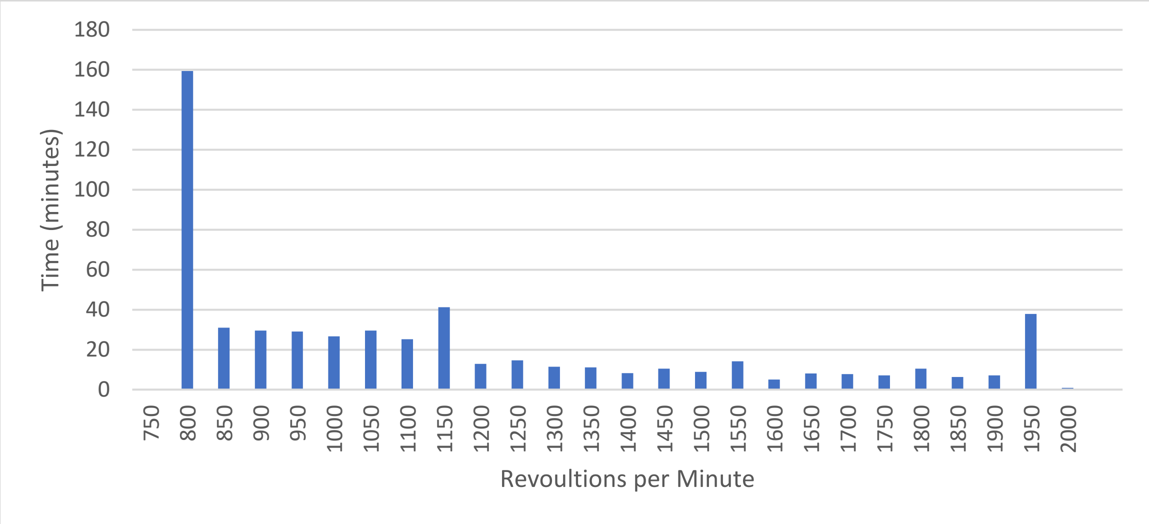

Figure 6: 15th of Junes RPM ranges

Below in Figure 16 are the total calculated time in the rpm ranges for the 16th of June and shows that the most common range for the RPM to occur in is between 800 – 850, with a total time of just under 140 minutes in total. The second most common range was, once again, between 1950 – 2000 RPM. This range is just under the maximum recording for the day which was 2000 RPM. The total time within this range was just over 35 minutes. Below in Figure 17, the calculated RPM ranges for the 1th of June is displayed.

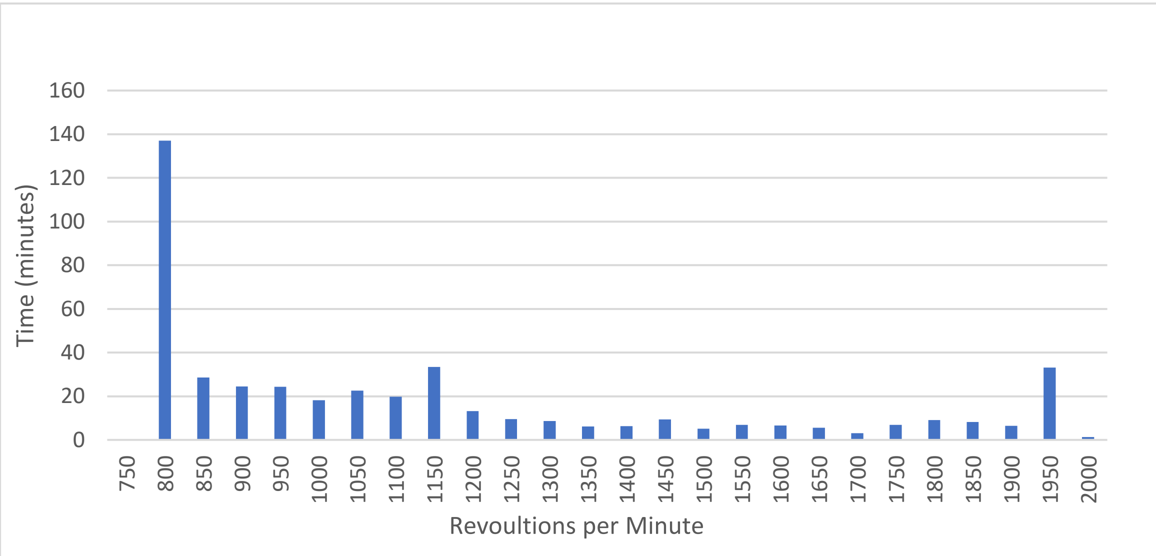

Figure 7: 16th of Junes RPM ranges

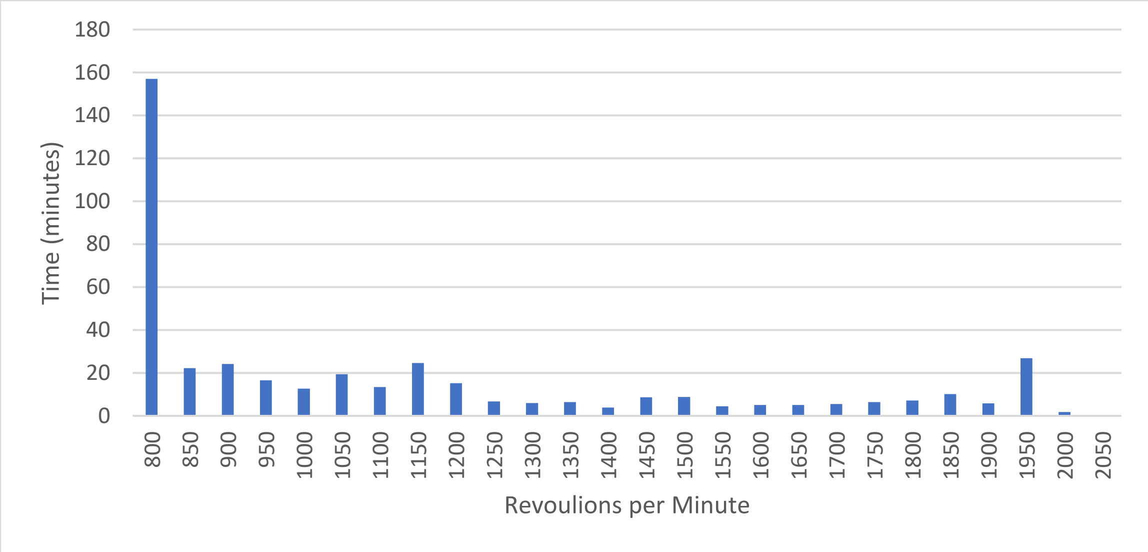

Figure 8: 17th of Junes RPM ranges

With just under 160 minutes in total, the largest occurring range of RPM is again the 800-850 RPM range. The second largest time was within the 1950 – 2000 RPM range with just over 25 minutes. This was just under the maximum rpm value of the day which was calculated at 2000. Figure 18 below displays the calculated range values for the rpm for the 18th of June.

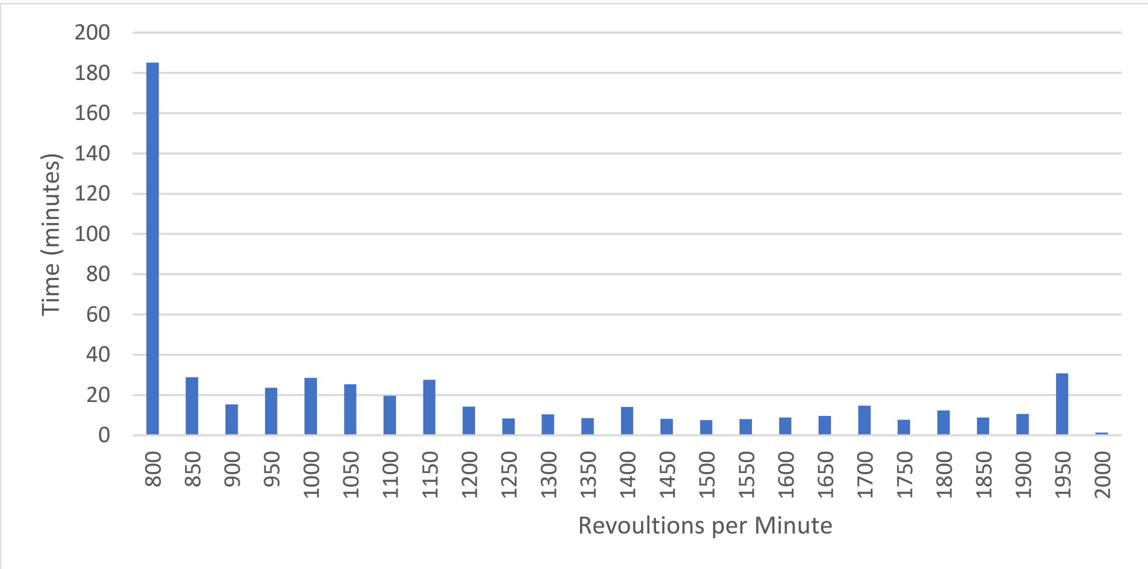

Figure 9: 18th of Junes RPM ranges

Figure 18 shows that the most common rpm range like the previous days is between 800 – 850 RPM. It has a total time of over 3 hours within the range and again, like the previous days the 2nd largest range is close to its maximum for the day between the range 1950 – 2000. The week from the 14th – 18th of Junes rpm values were combined and are displayed in figure 19 below.

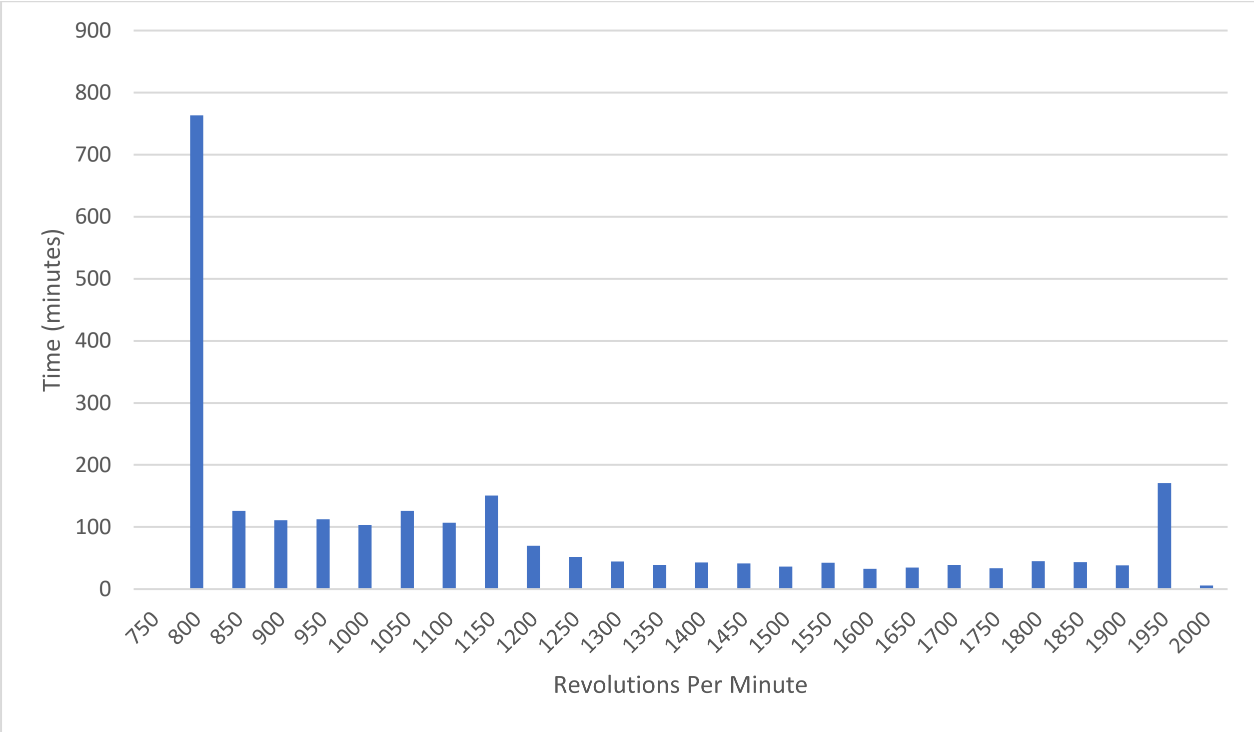

Figure 10: 14th - 18th of Junes RPM ranges

Figure 19 shows a very similar shape to the graphs seen in figures 14 – 18. The total time within the most common range of 800 – 850 was 763.6 Minutes which is almost 6 hours. In Table 7 below the time spent within each range is displayed as a percentage of the whole time the yarder was recording RPM values.

Table 7: The percentage of time the yarders RPM is within a given range

RPM Range	750	800	850	900	950	1000	1050	1100	1150
Percentage time in range	0.02%	31.64%	5.23%	4.60%	4.68%	4.28%	5.23%	4.43%	6.25%
RPM Range	1200	1250	1300	1350	1400	1450	1500	1550	1600
Percentage time in range	2.89%	2.14%	1.85%	1.62%	1.78%	1.72%	1.50%	1.76%	1.35%
RPM Range	1650	1700	1750	1800	1850	1900	1950	2000	
Percentage time in range	1.43%	1.61%	1.39%	1.88%	1.80%	1.59%	7.08%	0.24%	

Table 7 shows that the largest percentage of time spent for the whole week is within the 800 – 850 RPM range with 31.64%. The second largest is in the 1950 – 2000 rpm range with 7.08% of time. 15 out of the 26 ranges (57.7% of the total range of the rpm measured throughout the whole week) contained a total of 33.4% of the time within its range (1200 – 1950 RPM). Within the range of 800 - 1200 RPM 8 of 16 ranges (30.8%) is where the yarders revolution per minute was operating for 66.33% of the time. This can be explained by what is seen in Figure 20 below.

Figure 20 shows the carriage position in blue and the rpm values in red. The values between the range 800 – 850 occur when the carriage is at that landing and therefore the yarder is idle. The range between 1950 – 2000 rpm occurs the second most and this can be seen occurring at the start of the

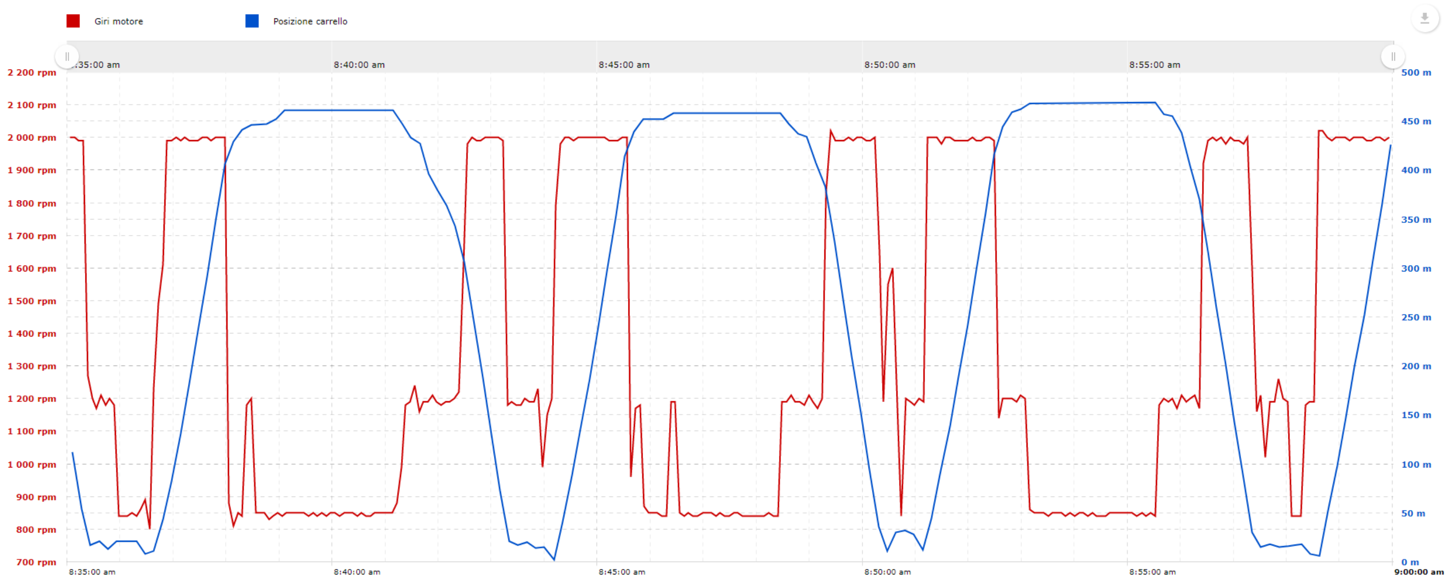

Figure 11: Proemion portal graphic of Rpm and carriage position

pulling of the wood towards the landing and right at the start of the cycle when the trolley is moving back out to pick up more logs/trees.

Discussion

Throughout this project, a large quantity of results has been produced through data manipulation from exported data off the Proemion portal. This data has come from a live feed connection to a Valentini yarder. With the amount of data available, there is an almost endless amount of data that can be processed to produce more values and figures. The results that I have produced are not the limitations of the possibilities and they will be discussed below. Forestry 4.0 Is the fourth industrial revolution in the forestry sector, for this revolution to happen a key step is the large-scale data manipulation of live feed data. This project highlights some of the possibilities available in this area.

The calculation of the SMH and PMH from the carriage position is a helpful tool not necessarily for the Valentini manufactures but for the crew using the yarder and the people / person managing the crew. This is because it will help with contract management and can be used as an audit technique to see if the crew is working as many hours as they are reporting or are contracted to do. The manager even has the possibility to tell if there is too much downtime for lunch breaks. This information can also be beneficial for the manufactures as in the future it will produce lifetime expectancies almost down to the second. This information will help create accurate depreciation models so second-hand buyers and sellers can have a reasonable price model. It could also provide as an evidence source for insurance claims for both parties, e.g if the yarder broke 2000 PMH before the mean lifetime of the model does, the physical evidence of this is clearly visible.

The fuel use calculations and results open up the possibility to the Valentini manufactures to have up to date fuel consumption statistics. Figures such as a yarder on average can pull 32km worth of extraction distances on a full fuel tank. It will be beneficial for costing of the yarder as It has accurate fuel use for day to day yarder use. The fuel use data can also be monitored and used as a baseline measure where other techniques in the harvesting chain can be tried to see if they save or cost fuel.

Using the Carriage position data, a relationship between cycle time and extraction distance was calculated. The relationship is Cycle Time = 3.93 + 0.0013 x Extraction Distance. This was calculated using the data from the 14th – 18th of June, with a sample size of 221. Extrapolating the data to an extraction distance to 0 metres shows an unload and load time of 3.9 minutes. This result is logical when compared to the results of a time study of a Valentini yarder. The yarder had a mean loading time of 271 seconds and a mean unloading time of 90 seconds, for a total time of 6 minutes and 1 second (Spinelli, Visser, Magagnotti, Lombardini, & Ottaviani, 2020). To get greater accuracy on the cycle times the cycles should be broken down into 4 areas: out haul, loading, inhaul and unloading. However, using the cycle time as a whole or breaking it down further into 4 sub parts still does not guarantee an accurate result. This is due to not being able to tell what is happening all the time with the yarder by just looking at the data, for example it is very hard to understand why there is delays in the cycle or stoppage completely (apart from obvious stops for breaks).

The method used to clean the data by removing data which was unexplainable or an outlier may have led to a creating a relationship in which predicts an unload and loading time that is too short. One variable which was not available that would be hugely beneficial for the future is load size. This could be done by correlating the data from the next step in the harvesting chain, which is likely a processor. The load size data along with the calculated cycle times and extraction distances offer a much more complete productivity calculation possibility. There is also potential to add a camera or link one that that's already there to the live data feed. This will allow for further accuracy when the data takes an unexpected turn. The camera is checked to understand if it is a breakdown or just slow work being done. This would mean that the cleaning of the data would be more accurate as only irrelevant information will be disregarded when calculating cycle times amongst other things.

The results of the rpm calculations produced a clear picture. For all 5 days the results were almost identical. The yarder worked within the 800 – 850 rpm range for 31.64% of the sample size time, this was when the carriage was not moving. For 7.08% of the sample time the yarder worked between the 1950 – 2000 revolutions per minute range. This was when the carriage began to move away or towards the yarder. Most engines deteriorate faster the greater the time spent at high RPM values, so the manufacturer will be pleased to know that the yarder seems to only run at close to its maximum RPM for short times and only when accelerating from a stop, this will increase its longevity. The fact that the yarders engine runs for the majority of time in 2 RPM ranges, it could be possible to better design the yarder knowing what the engine is going to be exposed to through the full cycle of pulling trees / logs to the landing. The total revolution data will be helpful in the long run as it can create a timeline of completed revolutions until maintenance is required or failure is expected. This will help prevent future large-scale delays/downtime.

Future research

In the Future to continue developing from the findings of this research paper, I would suggest including piece size data, load size and camera data in the live feed data readily available. That alone would enable the ability to do productivity studies from anywhere with internet access in a much shorter time and cost. This would allow manufactures and harvesting managers to have up to date knowledge of what causes the greatest productivity for crews and machines. Slight changes could be made and their impact on the productivity and efficiency monitored. This could be things such as rigging configurations or number of crew members.

Automated recording devices connected to the live feed data is also a future step. They could be programmed to record the time while working to automatically calculate the PMH. The recording devices could be set up to have ranges in which they should record. So, when the yarder reaches these ranges for whatever variable the time it is within the range is known instantly. An example would be recording when the carriage position goes below a certain distance (5 meters) and that would be the total unload time. Another example would be to record when the RPM reaches above 2000 RPM as that is in the range above the recorded max, meaning that the yarder is working harder then it normally should.

Conclusion

The aim of this report was to use the live data provided by the Valentini yarder company and find beneficial results and future developments. What was found was that there is great potential to develop the data manipulation of the live feed data to take a big step towards Forestry 4.0. Through the research done in this report, it is shown that there is a possibility to use the data to complete traditional productivity studyies from anywhere around the world with internet access. This saves time and money and increases safety. The results from this report shows a relationship between cycle time and extraction distance to be the following. Cycle Time = 3.9316 + 0.00129 x Extraction Distance.

Along with the cycle time and extraction distance relationship, the yarder was found to be able to pull 32.0 kilometres of extraction distance on a full fuel tank. On average, the yarder operates majority of the time in 2 ranges 800 – 850 and 1950 – 2000 RPM and the SMH and PMH are 43 hours and 5 minutes and 36 hours and 46 minutes respectively for the week used in the sample.

The ability to transfer live data from a yarder to anywhere around the world using the internet ss proven to be very beneficial, and is a huge step in Forestry 4.0 as it opens up the possibility for live corrections when the data is abnormal. This report has showed some of the many possibilities available with the data. Although this data is readily available for this Italian yarder in Italy. New Zealand is far behind in developments towards live corrective data. The main reason which was stated in the literature review earlier in the report, is the lack of coverage around New Zealand forests.

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