Estimating Winch-assist Utilisation using GPS Tracking

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the requirements for the degree of Bachelor of
Forestry Science with Honours by:

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1.0 Abstract

Winch-assist systems have become increasingly common in New Zealand as the drive to mechanise forest operations increases, with the aim of reducing accidents and improving the productivity of tree felling on steep slopes. Utilisation rates of forestry machines aid both management and operational decisions, as well as providing an understanding the frequency machines are used. Highlighting factors that influence utilisation rates is crucial in improving the productivity and efficiency of not only the individual machine, but the entire operation.

The results from this study aim to improve the understanding of how often winch-assist machines are utilised, as well as identifying factors that influence their utilisation. This study also aimed to determine how accurate GPS systems are at estimating utilisation rates, as a form of automated data capture that could potentially replace the traditional manual methods.

TeletracNavman GPS units were installed in a purpose built Caterpillar 552 felling machine, with self-levelling capabilities, and a Tractionline winch-assist machine (Hitachi 290 base). These GPS units recorded data used to derive two utilisation rates of the Tractionline winch-assist, based on different criteria relating to machine use. Utilisation Rate 1 was 60%, and derived for just the 88 days the winch-assist and felling machines worked together. Utilisation Rate 2 was 43%, and derived based on the potential time the winch-assist could have been used during the study period; including a total of 35 days the winch-assist was not used at all. The study highlighted three main factors that influenced the utilisation rate of the winch-assist. These factors were derived from Utilisation Rate 1. The main factors found to influence Utilisation Rate 1 of the winch-assist were:

- Frequency the winch-assist wasn't used.
- Area felled/day.
- Delays
    - Non-operational winch moves
    - Machine Idle

Keywords: Winch-assist, EMS Tractionline, Steep Slope, Tree Felling, GPS, Utilisation Rate.

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3.0 Introduction

3.1 Background

Operating forest harvesting machinery is invariably very expensive and one key metric for minimising the ownership cost component is ensuring a high level of utilisation. However, harvesting systems are complex and individual machines in the system can often be delayed by repair and maintenance or simply awaiting a task that is being constrained upstream or downstream of the production line (i.e. mechanical and operational delays, respectively). Machine utilisation drives management decisions such as machine purchase and costing (Spinelli & Visser, 2007), productivity targets, payment, and distinguishing between alternative machines (Amishev & Dyson, 2018). Most productivity studies of harvesting systems or machinery report utilisation rates and over time there is a lot of information for common equipment including cable yarders, harvesters and skidders. However, for relatively new systems such winch-assist machinery there is almost no such information. Winch-assist machines are utilised without an operator in the cab, and move very little if at all during each shift. For these reasons, measuring the utilisation of a winch-assist machine can be inherently difficult. Unfortunately, only a handful of studies have been carried out regarding the utilisation of winch-assist machines.

Traditional methods for establishing utilisation usually consist of someone on-site observing and/or recording what a machine does for a given period of time, also known as a time and motion study, or a work study. While this method is accurate, it is also both labour intensive and time consuming and as such these studies are typically constrained to just a few days of data collection. For studying felling systems the ability to be in an optimal position is also often compromised by the requirement to be a safe distance from operational equipment; a minimum of two tree lengths if observing tree felling.

Winch-assist systems are not new to the forest industry (Visser & Stampfer, 2015) and in New Zealand they have become increasingly common over the past 10 years in an effort to increase the range of ground-based harvesting systems (Visser, Raymond & Harrill, 2014). This has also allowed a more mechanised approach to operational forestry in a bid to reduce serious harm incidents which typically involve personnel on the ground. Winch-assist systems are unique in that they are often not required all day, every day. They are only used to support the movement of machines up or down a slope that exceeds its own ability to traverse safely or efficiently. It has recently been highlighted that there is limited information regarding the utilisation of winch-assist machines in New Zealand, nor is there any information on the factors which influence their utilisation of these systems.

3.2 Problem statement

Pan Pac Forest Products Limited currently pay a day rate for the operation of their contractors' Tractionline winch-assist machine. The day rate method means that a machine is paid a fixed rate, regardless of whether it is being utilised or not. The alternative to a day-rate payment method is the more common per-tonne method, where contractors are paid a logging rate based on production per day. Whilst Pan Pac are aware that the machine is not used every day, the level at which the machine is currently utilised remains un-known.

Understanding this utilisation rate is fundamental in determining the steps required to improve their efficiency and productivity. By having a low utilisation rate Pan Pac are not only paying for a machine that isn't working, but a motor-manual tree faller is also working on a steep slope; a scenario that can be avoided by utilising this winch-assist machine. Whilst motor-manual tree falling can be undertaken safely and correctly, the chances of injury or serious harm are greatly increased when not inside a machine. The focus of this study from Pan Pac's point of view is to determine the utilisation rate of a piece of equipment that is:

a) Capable of removing a man from steep harvesting settings.
b) Increasing the safety of mechanised harvesting systems.
c) Currently paid a fixed rate, regardless of utilisation.

This study aims to identify how winch-assist machines can best be utilised based on the current utilisation rate of a Tractionline winch-assist machine, determined using data captured by automated GPS technology. Three research questions have been developed for this study:

1. How effective are TeletracNavman GPS units at estimating machine utilisation data?

2. What is the current utilisation rate of a Tractionline winch-assist machine?

    a) What influences this utilisation rate?

4.0 Literature Review

4.1 Mechanisation & Winch-assist systems

The introduction of mechanisation to the forest industry in New Zealand has been recorded as early as the 1970s, with a drastic increase over the past 15 - 20 years (Riddle, 1995; Forest Growers Research, 2017). Factors influencing the historic and more recent drive for mechanised operations include:

- Historically, there was a shortage of skilled labour to deal with a heavy manual-delimbing workload, providing one of the initial drivers for mechanisation early in the industry (Riddle, 1995).

- Increasing the efficiency and productivity or harvesting operations (Visser, 2017). This is an indirect and also incentivising benefit associated with the drive to increase worker safety.

- Utilising technology and machines to reduce the frequency of accidents and injuries associated with tree felling, delimbing (manual) and breaking out (Riddle, 1995; Forest Growers Research, 2017; Visser, Raymond & Harrill, 2014).

The mechanisation of both ground-based and cable logging operations continues to increase. Mechanised felling of cable logging operations rose 7% from 2016 to 2017, to a total of 35%; and remained steady at approximately 85% for ground-based operations. The major factor influencing the increase of mechanised felling on cable logging sites was terrain. It was recorded that all swing yarder operations sampled had adopted mechanised processing in 2017, and mechanised processing was being used at 92% of all cable logging operations sampled, a decrease of 4% from 2016 (Visser, 2018). Overall, mechanised felling currently occurs in 54% of operations, with mechanised processing present in approximately 95% of forest operations in New Zealand (Visser, 2017).

A winch-assist machine in New Zealand is typically designed on a used bulldozer or excavator, that has been modified with either one or two drums of wire rope replacing the machines factory counterweight. The wire rope/s are connected to a felling machine via an engineered “drawbar”, where the purpose of the winch assist is to provide traction on steep slopes for the felling machine to traverse both safely and efficiently.

Figure 1: *EMS Tractionline winch-assist machine observed during this study.*

Winch-assist systems are not new to the forest industry (Visser & Stampfer, 2015) and in New Zealand they have become increasingly common over the past 10 years in an effort to increase the range of ground-based harvesting systems (Visser, Raymond & Harrill, 2014). Winch-assist systems also increase the possibility of mechanised felling on cable logging settings. As of mid-2017 there were approximately 60 winch-assist machines operating in New Zealand (Visser, 2017). Three variations of winch-assist machines are developed and manufactured in New Zealand, all of which are available to purchase commercially locally and world-wide. A number of innovative contractors have also developed winch-assist machines, tailored for use in their operations.

The adoption of winch-assist machines used in mechanised felling operations has recently been measured for the first time in New Zealand. Preliminary results indicated that approximately half of cable logging operations using mechanised felling were supported by winch-assist machines; however only one-third of cable logging operations actually have these machines available (Visser, 2018). The preliminary results highlight the potential for the increase of winch-assist systems, reiterating the importance of data such as utilisation rate and productivity for these machines.

4.2 Global Positioning Systems

The use of Global Positioning Systems (GPS) for forestry applications both globally and in New Zealand are well recognised. A major use of GPS technology in the New Zealand forest industry is remote sensing and mapping applications. However, the installation of GPS technology in forest machinery is becoming increasingly more common (Hejazian, Hosseiini, Lotfalian, & Ahmadikoolaei, 2013 ; McDonald & Fulton, 2005). When used on forest harvesting machines, data collected from a GPS can improve forest engineering design and management decisions based on machine performance data (Taylor, McDonald, Veal, & Grift, 2001). The use of GPS technology in forest machines has the ability to capture the required data automatically and accurately, without the costs and risks associated with an employee involved in the data collection process (Veal, Taylor, McDonald, McLemore, & Dunn, 2001); (Gallo, Grigolato, Cavalli, & Mazzetto, 2013).

The accuracy of GPS systems within forested environments is often questioned. One of the three main pieces of information recorded in this study is machine location, hence the importance of an accurate GPS system. Forests are a prime example of a less-than-ideal location for the use of GPS technology due to: canopy cover interfering or blocking signal view and windy conditions, where the canopy movement may cause multi-path effects (GPS signal bouncing off several features, resulting in a set of multiple copies of the same signal) (Sigrist, Coppin, & Hermy, 1999). Often, these issues are managed by placing the GPS receiver or antennae as high as physically possible on the designated vehicle or machinery (Sigrist, Coppin, & Hermy, 1999).

The use of automated technology for tracking key metrics such as productivity and utilisation on forest machines continues to increase, with a range of makes and models currently documented. The MultiDAT is an automatic data logging system designed to meet the needs of owners and managers of heavy equipment. MultiDAT’s are a user-based system, and have been used to verify the impact of site conditions on utilisation rates and productivity of harvesters and forwarders (Ghaffaryn, 2015; Dyson, 2017), as well as monitoring metrics such as engine speed, engine idle, and travel times of logging trucks (Kryzanowski, 2018). Oregon 550 units are a fleet management system developed by Garmin Company, and have been used to monitor the chipping and transportation of wood fuels (Hejazian et al, 2013). The Trimble Pro XR external GPS was used to investigate methods for continuous autonomous monitoring of harvest system productivity, as an alternative to traditional time study methods (McDonald, T, 1999). The TeletracNavman QT200 is a fleet management GPS system that is capable of monitoring productivity, compliance and Road User Charges (RUCs), as well as providing feedback on driver behaviour and safety (TeletracNavman, 2018).

In 2015 Navman merged with GPS fleet tracking company Teletrac, rebranding as TeletracNavman in 2016 creating one of the world's largest telematics organisations (TeletracNavman, 2018). TeletracNavman tailors the use of telematics using GPS technology to derive a range of work functions (including utilisation), on a range of vehicles and machinery (TelertracNavman, 2018). The use of remote technology to derive information such as utilisation provides accurate, real time updates to user interfaces via the satellite network; which is useful for forest locations due to the unreliability of the current mobile network in remote forest locations in New Zealand.

4.3 Utilisation Rate

The level of mechanisation within the forest industry in New Zealand has continued to increase; whilst the traditional methods used for collecting utilisation have remained much the same (Hejazian et al, 2013).

An accurate estimation of machine utilisation is extremely useful for deriving harvesting system costs (Ghaffaryan, 2015). Utilisation is described as the ratio of productive machine hours (PMH) and scheduled machine hours (SMH) (Holzleitner, Stampfer, & Visser, 2011) where the difference between PMH and SMH is the sum of the delays. Utilisation rate provides a metric that measures the efficiency of a piece of machinery or harvesting operation based on a typical work day. These ratios or values of utilisation are used by contractors and forest managers alike to determine productivity, as well as highlighting trends or bottlenecks within operations.

Machine utilisation drives management decisions such as machine purchase and costing (Miyata & Steinhilb, 1981), productivity targets, payment, and distinguishing between alternative machines (Spinelli & Visser, 2007). Most productivity studies of harvesting systems or machinery report utilisation rates, and over time there is a lot of information for common equipment including cable yarders, harvesters, processors, and skidders (Ghaffaryn, 2015; (Holzleitner, Stampfer, & Visser, 2011). However, for relatively new machines such as winch-assist, there is limited information regarding utilisation rates.

4.4 Work Studies

4.4.1 Time and Motion Studies

Detailed time and motion or shift level studies are the traditional and most common methods used for data collection of forest machinery (Olsen , Hossain, & Miller, 1998). Detailed time studies are inherently short and may not accurately capture certain phenomenon, such as delays (Bergstrand, 1991). While it is possible that time and motion studies capture delays, these are often less than 10 minutes in length, and are not the focus of this type of study. Traditional manual time and motion studies are typically time consuming, costly, limited in duration and involve potentially hazardous work in close proximity to the machines being studied (Strandgard & Mitchell, 2015).

Shift level studies are similar to detailed time studies. The major differences between each method is shift level studies capture delays greater than 10 minutes in length as they are carried out over a period of weeks to months, and provide a better estimate of long-term productivity (Dyson, 2017). Shift level studies can be carried out manually or automatically, where in the case of the former the operator completes a data sheet that has been provided during each shift. Benefits associated with shift level studies include accurate information provided by the operator and do not require an observer on-site. Conversely a disadvantage may be the operator forgets to, or incorrectly completes the data sheet as required. Shift level studies are generally the main technique used for long-term follow-up studies aimed at determining machine utilisation (Magagnotti & Spinelli, 2012).

While levels of technology and mechanisation increase in the New Zealand forest industry, the most common method of data capture for scientific studies still relies on the use of traditional time and motion studies. Recently, the use of automated and GPS technologies have challenged these traditional methods for capturing such data and information (Strandgard & Mitchell, 2015; Arlinger & Moller, 2014). Results from both the traditional method and GPS technology have been found to be comparable. However, each method has both advantages and disadvantages that must be taken into consideration (Arlinger & Moller, 2014). McDonald (1999) states that for an automated system to perform time studies, the system would require some way of identifying the time and location of specific, individual events.

Automated data collection methods address the reliability and accuracy of traditional time studies, however there are factors that affect the ability to compare both methods. An observer has the ability to verify the operator's actions by verbal communication as events of interest occur, where this is not yet possible with automated data collection methods (Arlinger & Moller, 2014). Other factors that must be considered when using automated data collection methods include the development of Key Performance Indicators (KPIs), data collection/transmission systems, and customised reports that generate the required information (Laforest, 2012). Whilst automation can capture data over a long period of time and at lower costs, it may be necessary to verify the data collected by implementing the traditional methods of time studies.

4.4.2 Delay Studies

Delays are defined as an interruption of the normal working process. Delays that occur in forest operations are often categorised as personal, mechanical or operational, the sum of which are often represented as a percentage of Scheduled Machine Hours (SMH) (Spinelli & Visser, 2007). A fourth delay type is those that are caused by undertaking the study itself (e.g. Delays due to the research activities), however these are generally excluded from the analysis or not measured (Magagnotti & Spinelli, 2012). Measuring delays that arise during harvesting operations can be used to explain factors that affect utilisation. Delays are recognized as being one of the major factors that limit productivity in most operations and are therefore, an integral part of most time studies (Spinelli & Visser, 2007).

An adequate study length is important when recording delays. To provide an adequate estimate of the percentage of time associated with each delay, delays can be recorded using the same method to a detailed time study (Hossain, 1998). As previously noted, detailed time studies capture minor delays (<10 minute), and shift level studies capture major delays (>10 minutes). Whilst detailed time studies are more effective at capturing minor delays, study length is often an issue. For this reason shift level studies are the preferred study method for capturing delays, as they are typically carried out over longer periods of time. The advantage of using an automated data collection system is the ability to accurately capture both minor and major delays, without the cost and time associated with traditional methods (Gallo et al, 2013; Hejazian et al, 2013).

4.5 Previous Studies

Whilst the use of GPS technology is becoming increasingly more common for work studies of forest machinery, the use of such technology to determine utilisation rates is still a relatively new concept; especially for winch-assist machines. Other uses focus on: the accuracy and reliability of this technology, the influence canopy cover has on GPS technology, accurately tracking machine position within a forest, as well as a measure of machine productivity. The main trend identified across previous studies was the potential that GPS technology has to replace traditional methods of data collection (Laforest & Pulkki, 2014; Ghaffaryn, 2015; Gallo et al, 2013; Hejazian et al, 2013).

Previous studies have determined a range of values for the utilisation of forest machinery. However, these metrics can vary depending on the execution and methods of a study. The implementation of these technologies within wood procurement provides valuable information that would help improve operational efficiencies and lower costs (Laforest & Pulkki, 2014). Laforest & Pulkki (2014) concluded that utilisation rates of skidders, feller-bunchers, processors and gravel trucks ranged from 74.5% and 79.3%, where data was captured and recorded using the MultiDAT data logging system. The Utilisation Rates of a forwarder and harvester were 81.1% and 77.3% respectively (Ghaffaryan, 2015), which were similar to results published by (Holzleitner, Stampfer, & Visser, 2011) of 78.0% and 70.0%.

Only two studies regarding the utilisation rate of winch-assist machines have been published. The first in British Columbia, Canada, where it was reported that the utilisation rate of a DC Equipment Falcon winch-assist machine was 71%; however suggested anecdotally that this could range between 40% - 70% (Amishev & Dyson, 2018). The second case was from a survey conducted in New Zealand, where contractors were asked how often their winch-assist machines were used on a monthly basis. The results ranged from as low as 17% through to 83% utilisation, with an average utilisation rate of 45% (Harrill, Reriti, & Visser, 2018).

The limitations surrounding current figures of utilisation for forest machinery are that the majority of them do not correspond directly to winch-assist machines. To verify the real impact of operational factors on long-term machine performance, more detailed machine utilisation case studies combined with machine productivity records are required (Ghaffaryan, 2015). Regardless, the data collected from previous studies provide a useful benchmark for the utilisation rate of winch-assist machines.

5.0 Methodology

5.1 Operations and Equipment

5.1.1 SMH

The typical work day for the operator of the felling machine is 06:00am - 15:00pm, Monday to Friday. This work day sometimes varied, and Saturdays were also often worked. From the literature, it was stated that the Scheduled Machine Hours (SMH) of forest machines on average were 8.5 hours per day. To remove any complications regarding SMH of the winch-assist and felling machines, SMH have been assumed 8.5 hours for each working day the winch-assist and felling machines were used, both together and individually. (Visser, 2017; Visser, 2018).

5.1.2 PMH

Productive Machine Hours (PMH) were estimated using machine “On” and machine “Off” data recorded by the GPS units, as well as the data being manually reviewed. The manual verification of such delays and events were carried out using the TeletracNavman reporting software and user interface Director. The PMH for each working day of the winch-assist and felling machine have therefore been estimated using GPS data, with the assistance of the reporting software associated with these GPS units.

5.1.3 Operator

The operator of the felling machine remained the same during the study period. The operator has approximately two and a half years operating the felling machine, and two years’ operating the felling machine in conjunction with the winch-assist. The two machines were often walked between multiple crews working in the same forest. When this occurs, if a second employee is available they will walk the winch-assist machine with the operator of the felling machine in order to reduce the time the operator would have to walk both machines if he were to move them both himself.

5.1.4 Felling System

Tree felling on steep slopes with a winch-assist is a two machine system. Specifically, the two machines observed during this study were a purpose built Caterpillar 552 felling machine, with self-levelling capabilities. This felling machine worked in conjunction with a Tractionline winch-assist machine (Hitachi 290 base) designed and manufactured in Rotorua, New Zealand, by Electrical & Machinery Services Ltd (EMS). The Tractionline is a two-rope winch-assist system (Figure 1 & Appendix 1).

Whilst the felling machine operated almost every scheduled work day, the winch-assist machine was used periodically when the felling machine was operating on steeper slopes. The winch-assist provides increased traction and also an increased level of safety when operating heavy machinery on steep slopes. Both machines are owned and operated by D G Glenn; a harvesting contractor for Pan Pac Forest Products in Hawkes Bay, New Zealand. As contractor D G Glenn have multiple crews operating for Pan Pac, this specific felling machine does not work for a single crew, but is transported between multiple crews/forests as it is required; both with and without the winch-assist machine depending on the terrain and settings. These machines were the only two observed for this study.

5.1.5 GPS units

TeletracNavman supplied two QT200 GPS units as part of a trial package for Pan Pac Forest Products in 2017. These units were installed into both the 552 felling machine and the winch-assist on the 6th of September 2017. For the first six weeks post-installation there were a number of connection problems with the units. These issues were due to the installation contractor being unfamiliar with the technology, and took longer to remedy than anticipated. The units were fully operational and collecting data by the 7th December 2017.

The QT200 units are designed for fleet management purposes, however have previously been used in heavy machinery. The GPS units were programmed to record data at one minute intervals, when the machine was turned on. The GPS units also have the ability to track movements when the machine is off, for example when it is being moved on a transporter from one forest to another, these movements are recorded at the same 1 minute intervals as if the machine was on. Machine “On” and “Off” times were recorded by the ignition in both the winch-assist and felling machines. These GPS units were initially intended to be able to measure machine utilisation, by determining between “work” and “idle” for both machines, however it became apparent that TeletracNavman’s reporting software Director was unable to distinguish these two metrics.

A CoNex connection was established in the felling machine, to determine when the machine was working or not. CoNex is an additional wiring system, separate to the GPS units itself. The benefits of a CoNex connection is that it can be wired to anything with a switch, to determine the corresponding metrics. In this case, the CoNex connection was wired to the hydraulic lock-out, or bail arm of the felling machine (Appendix 2). The concept behind wiring this connection was that when engaged, the machine is in-operable and therefore not working, and when disengaged the machine is assumed to be working. This connection was unable to be made in the winch-assist machine due to the unique nature of how they are used.

The problem was highlighted in January of 2018 and TeletracNavman were able to tailor their reporting software to try and capture these metrics. Whilst there was some success in integrating the new metric, the aim was to refine this process even further so that this information could be recorded automatically, and be displayed by the reporting software. This was unable to be achieved prior to the data analysis for this project, therefore all data analysis was done manually using the Director reporting software, and the automatically recorded “On” and “Off” times. Whilst the reporting software was unable to be developed in time for this project, there is an ongoing relationship between TeletracNavman and Pan Pac, where it is hoped that the methods of data collection, desired outcomes and results from this project will provide valuable information for the companies moving forward.

5.2 Study Sites

During the study period the winch-assist operated on 15 different sites across the Hawkes Bay region, all of which were forests owned by Pan Pac Forest Products or woodlots acquired by the company. The winch-assist worked for multiple crews across various settings within these sites. The following four study sites cover a range of operating conditions, and are a random sample of all sites the winch-assist worked during the six month study period. Maximum slope and felling distance were recorded on-site both during and after harvesting had occurred (Table 1).

Table 1: *Summary of study site characteristics for the winch-assist felling system.*

	Maximum slope (degrees)	Maximum distance felling machine from winch-assist (m)
Site 1	44	180
Site 2	46	130
Site 3	34	160
Site 4	28	88
Average	38	140

5.2.1 Slope and Site Conditions

A more detailed analysis of slope was also conducted using the latitude and longitude data recorded by the GPS unit in the felling machine. These latitude and longitude recordings were captured at the same 1 minute intervals as other data. These data were used to determine slope at each point that was recorded, providing an indication of what slopes the operator was working on, and for how long.

It has been assumed that all slope values recorded between 0 - 5 degrees (1,199/25,631 points) were when the felling machine was not operating, and therefore have been removed from this analysis. Slope has been classified using the following 3 categories:

- **5˚- 21˚:** Slope "Easily" traversed by tracked machines (NOT winch-assisted).
- **22˚- 44˚:** Working range for felling machine operating with winch-assist.
- **≥45˚:** Maximum safe working slope as specified in the Tractionline Operators Manual.

Understory vegetation across sites varied from minimal to no impairment for the operator, to extreme cases where small woody shrubs were above the cab of the felling machine. On a number of sites where the terrain was extremely steep and the understory dense, the operator would exit their machine briefly to inspect the slope/conditions around the felling machine prior to proceeding down the slope.

5.3 Data Collection

All data analysed for this study was that collected from the EMS winch-assist machine. Data from the 552 Felling machine was used to verify when the winch-assist was used, and whether or not the two machines were working together or not. All data referred to from this point onwards is that of the winch-assist machine, unless otherwise specified.

5.3.1 GPS Data

The data collection period for this study initially commenced on January 1st 2018, and ceased 31st July 2018. The GPS units were set by default to record data at five minute intervals. During the month of January this was decreased to one minute intervals to increase the accuracy of measurements. For the purpose of continuity, the data period was reduced from January 1st - July 31st 2018 to February 1st - July 31st 2018, providing six months of data recording at one minute intervals. The TeletracNavman GPS units are able to record a wide range of data. Data captured that was necessary for this study were:

- Machine location.
- Machine "On" time.
- Machine "Off" time.

The difference between machine "On" and machine "Off" time for the winch-assist and felling machines was determined to be the Productive Machine Hours (PMH) for each working day. This information was recorded by the ignition status of machines, and further refined using delay data that was manually reviewed (see section 5.3.2). Machine location data was used to determine whether or not the winch-assist and felling machines were working together. Location data was also used to determine how often the winch-assist was moved between forests/woodlots, and also to determine the number of locations the winch-assist operated from for the days it was operational.

As there is no current estimation of winch-assist utilisation, scheduled machine hours were assumed to be 8.5 hours each working day. The difference between SMH and PMH is expected to be the sum of the delays that occur during each work day. Data collected from the GPS units alone were not enough to be able to determine what influences the utilisation rate of the winch-assist machine. Therefore, a detailed delay study was carried out for three days to verify the accuracy of information from the reporting software Director.

5.3.2 Delay Data

A detailed delay study was carried over the period of the 9th, 10th and 12th of April, 2018. Machine "On" and "Off" hours have been used as the primary data to derive Utilisation Rate, however just because the winch-assist was "On" does not mean that it was necessarily working or productive. Whilst the GPS units between the two machines can identify when a machine is not working (i.e. a delay has occurred), they cannot distinguish the reason for the delay. Therefore, hours "On" indicated by the GPS unit is an imperfect estimate of PMH. A 3-day delay study was conducted to determine how accurately the TeletracNavman GPS measures delays, and to gain an understanding of what affects the utilisation rate of the winch-assist machine. Data for this delay study was recorded manually by an observer on each of the three days using a stopwatch and a delay study template (Appendix 3). The observer was in constant radio contact with the operator; as well as for safety reasons, this also allowed the operator to confirm why delays had occurred. Additionally, there were times that the observer could not see the operation visually due to safe working distances and limited safe zones. During these instances radio contact also proved invaluable.

Delays captured the by GPS units, as well as the delays that occurred during the 3-day delay study were represented by the following categories:

- Operational winch moves.
- Non-operational winch moves.
- Machine Idle.
- Other.

For consistency, delays captured during the delay study were categorised the same as those captured by the GPS units. These four categories have been used as they represent the three major delays associated with the winch-assist machine, and are also able to be derived by manually analysing the Director reporting software. Operational winch moves were defined as being any time the winch-assist was required to be moved whilst still attached to the felling machine, or moved for any operational purposes. Non-operational winch moves varied, as these accounted for the time that the winch-assist was walked between skid sites, to or from the forest gate for transport; essentially any move made by the winch-assist that was not deemed to be for operational purposes. All un-explained, non-movement delays were categorised as "Machine idle". Minor delays (<2 minutes), or delays that occurred infrequently were categorised as "Other". It is expected that the "Other" category will be where the majority of the difference between delays captured by the GPS units, and those that occurred infrequently and for very short periods of time during the 3-day delay study, will be highlighted.

5.4 Data Analysis

5.4.1 ANOVA

The statistical software RStudio was used to perform an analysis of variance, or ANOVA. An ANOVA is a statistical method used to test for differences between two or more means. This statistical method was used to determine if the factors corridor distance, winch-assist moves per day, or area felled per day influenced Utilisation Rate 1. Utilisation Rate 1 was used in this analysis as it represented the time the winch-assist was operational, the time that these factors could influence the utilisation rate. Factors were removed from the model based on a statistical significance level of $P \leq 0.05$, as it is expected that not all factors will influence the utilisation rate. A final model and linear equation were derived that identified which factors influenced Utilisation Rate 1.

5.4.2 DEM Transformations

Latitude and longitude data recorded for the time the winch-assist and felling machines worked together during the study period were manipulated and transformed using the statistical software RStudio. Location data were used to derive the slope for each of the 25,632 latitude and longitude points recorded during the study period from the GPS "Pings" that occurred at 1 minute intervals.

Figure 2: *GPS "pings" for one working day of the 552 felling machine, as shown in the reporting software Director.*

All 25,632 latitude and longitude points were recorded when the two machines worked together. These points were transformed into eastings and northings so that the data could be projected onto the New Zealand 15m x 15m Digital Elevation Model (DEM) in the statistical software RStudio. When projected onto the DEM, slope information was extracted for each of the 25,632 points of latitude and longitude providing a data set of slope values corresponding the areas the felling machine worked during the six month study period.

6.0 Results

6.1 Utilisation Rate

The study period was February 1st 2018 - July 31st 2018, with a total of 123 working days recorded during these dates. Of these 123 days, the winch-assist and felling machine worked together for 88 days; 72% of the time. Reasons the two machines didn’t work together during the remaining 35 days were:

- Weather
- Slope (i.e. Not steep enough to require winch-assist)
- Time spent on transporter between forests

As there was a significant proportion of the study period that the two machines did not work together, two different utilisation rates have been derived. Most forest machines operate almost every working day. However, winch-assist machines are often used periodically as they are required, often resulting in a number of days where these machines aren’t utilised at all. Two utilisation rates have been derived from this study, the first representing the days both machines worked together, and the second includes the 35 days they winch-assist was not used, as a total proportion of time the winch-assist could have worked during the study period. The need for providing two utilisation rates was justified by the significant period of time the winch-assist was not used, as providing just one of these values of utilisation would be insufficient and also misleading. Additionally, the winch-assist is paid for on a day-rate. This means that the winch-assist day costs are incurred regardless of whether it is used or not. This payment method further justifies the need to provide a utilisation rate that includes the days the winch-assist was not used at all.

Utilisation rate is the ratio between estimated PMH and SMH, where the difference between these two values is the sum of delays and time the winch-assist spends “Off” during each working day.

$$Utilisation\ Rate\ (\%) = \frac{PMH}{SMH} \times 100$$

The benefits for providing an estimation of utilisation rate for winch-assist machines include:

- Contractors looking at purchasing these machines are presented with an estimate of how much they can expect these machines to be used.

- In relation to the point above, this may dictate whether or not added extras available for the winch-assist are included or not (e.g. quick hitch for grapple); which would allow the machine to be capable of performing other tasks when it is not required for its primary purpose.

- To derive appropriate pricing/costing for the machine.

6.1.1 Utilisation Rate 1

The first measure of utilisation was derived using estimated PMH and SMH for the 88 days the winch-assist and felling machines worked together. The total SMH for the 88 days the felling machine and winch-assist worked together was 748.0 hours, assuming an SMH of 8.5 hours/day for this study.

Estimated PMH were the sum of the total time the winch-assist was recorded as “On”. The value for PMH excludes the sum of the delays, and also the time the winch-assist was not used during the day. The latter contributed a large proportion of time that affected PMH. Of the 88 days the two machines were used together, the winch-assist was “On” for 8.5 hours or longer on only 3 occasions. For a large majority of the time, the winch-assist was only used for a proportion of the day as required. The utilisation rate for the winch-assist machine when working in conjunction with the felling machine is 60%, or 5.1 hours of the 8.5 scheduled machine hours.

Table 2: *Utilisation Rate 1 for the EMS Tractionline winch-assist studied.*

PMH (88 days)	446.2 (hrs)
SMH (88 days)	748.0 (hrs)
Utilisation Rate 1	60%

6.1.2 Utilisation Rate 2

The second utilisation rate has been derived to represent the 35 days that the winch-assist was not used. For this reason, the value of PMH remains the same as Utilisation Rate 1. As with utilisation 1, the value for PMH excludes the sum of the delays, and also the time the winch-assist was not used during the day. The difference for this value of utilisation being SMH, where SMH was calculated based on the 123 days the felling machine worked during the study period; the total amount of time the winch-assist could have worked during the study period.

Table 3: *Utilisation Rate 2 for the EMS Tractionline winch-assist studied.*

Estimated PMH (88 days)	446.2 (hrs)
SMH (123 days)	1,045.5 (hrs)
Utilisation Rate 2	43%

The utilisation rate for a winch-assist machine when taking into consideration every scheduled work day, regardless of whether or not the machine is working, is 43%, or 3.6 hours of the 8.5 schedules hours. The 17% or 1.45 SMH difference between Utilisation Rates 1 & 2 highlights the necessity of providing two utilisation rates and how important it is to clearly outline how utilisation has been calculated. Figure 3 below, highlights these two Utilisation Rates given the criteria previously mentioned. The red line on Figure 3 represents Pan Pac's expectation for utilisation of the winch-assist machine (75%) prior to conducting this study.

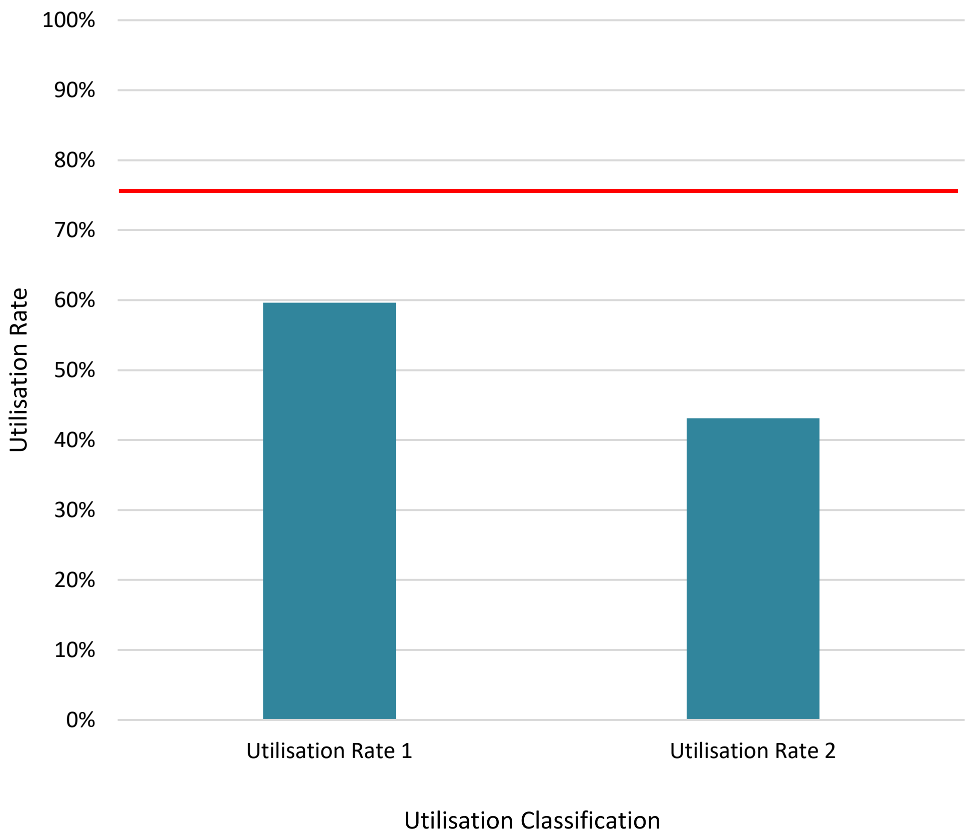


Figure 3: *Utilisation Rates 1 & 2 for the EMS Tractionline winch-assist studied.*

6.1.3 Monthly Utilisation Rates

Utilisation Rates 1 & 2 were also analysed on a monthly basis to determine if there were any monthly or seasonal trends that influenced utilisation. Table 4 outlines the difference between days the felling machine worked per month and the total number of days the winch-assist was used in conjunction with the felling machine. During the 6 month study period, the winch-assist and felling machine worked together for 88 days. The felling machine operated for 35 additional days; during these days the winch-assist was not used at all.

Table 4: *Total calendar work days/month compared to the days that were actually worked each month during the study period.*

	Days felling machine used	Days winch-assist & felling machine used
February	19	12
March	22	15
April	19	18
May	23	11
June	17	15
July	23	17
Total	123	88

Both Utilisation Rates 1 and 2 varied between months. Utilisation Rate 1 ranged from 53% - 68%, where Utilisation Rate 2 had a larger range of 33% - 59%. The month of May stands out more than others, with both the highest Utilisation Rate 1 and lowest Utilisation Rate 2. May alone represented 12/35 days the winch-assist went unused during the study period. However, when the winch-assist was used during May it was utilised the most, with an average work day ("On") time of 5.8 hours. Monthly trends were not found to statistically influence Utilisation Rates 1 or 2 of the winch-assist.

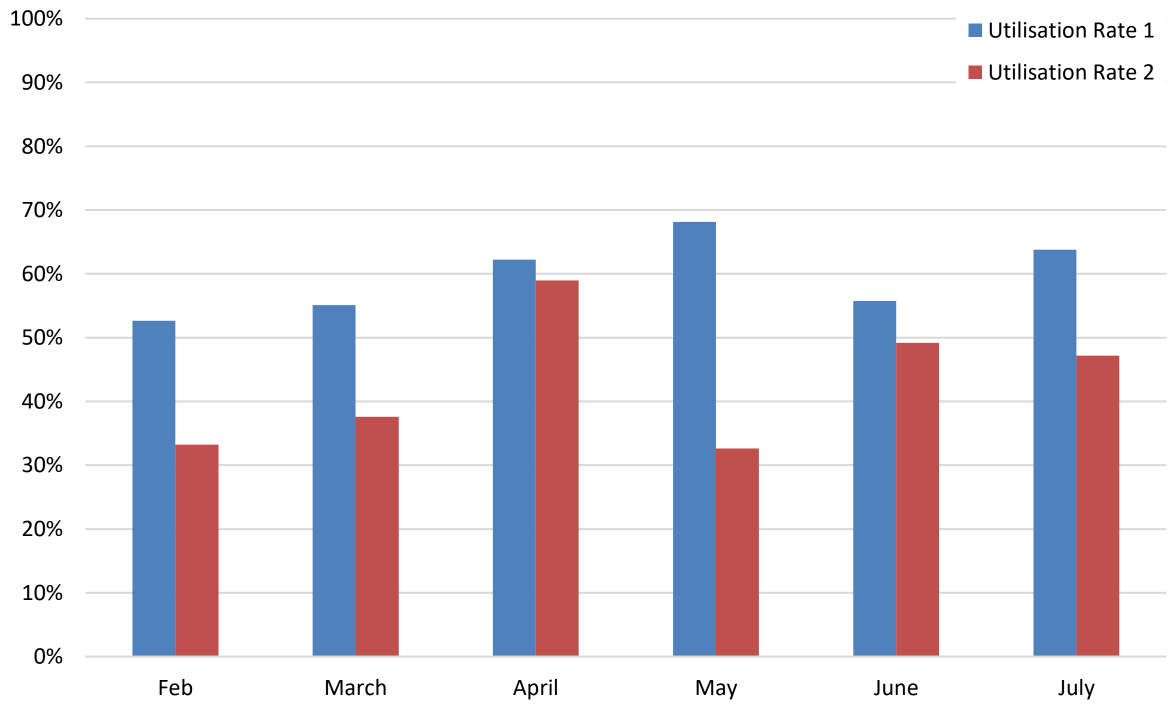


Figure 4: *Utilisation rates of the winch-assist for each month during the study period.*

6.2 Delays

6.2.1 Delay Study

A 3-day delay study was carried out on the 9th, 10th and 12th of April 2018. The aim of the delay study was to determine how accurately the TeletracNavman GPS captured delays, and to gain an understanding of the factors that affect utilisation rate of the winch-assist machine.

Delays were recorded and classified into one of four categories (Table 5). The categories were used in order to align with the delays that could be captured by the GPS units. The fourth category "Other" is a sum of all delays that occurred infrequently. The number of reasons why delays occurred is much higher for the delay study than those captured by the GPS. This is because a detailed delay study with an observer is able to capture all delays that occur during the day, as well as determining why they occurred. Whilst the GPS units can capture delays, the system is unable to capture some of the minor delays that occur; unless the GPS data is reviewed manually using the Director reporting software.

Table 5: *Comparison of delays captured by each data recording method.*

Navman GPS captured	**Delay Study captured**
Operational winch moves	Operational winch moves
Non-operational winch moves	Non-operational winch moves
Machine Idle	Machine Idle
Other	Other
• Winch-assist only used to access bottom of slope.	• Out of machine to check ground conditions. • Waiting for crew member to arrive. • Changing chain on felling head. • On radio (communication). • Checking winch-assist ropes.

Utilisation Rate 1 for the Tractionline winch-assist machine on Day 1 of the delay study was 72%. The winch-assist worked for a full day with the felling machine, with 6.1 recorded productive machine hours. On Days 2 and 3 the winch-assist was only used for a portion of each day, with utilisation rates of 37% and 32% respectively. The average utilisation rate of the winch-assist machine across the 3-day delay study was 47%.

Table 6: *Variation in Utilisation Rates during the 3-day delay study.*

Day	Delay Study Utilisation Rate (%)
1	72
2	37
3	32
Average	47

During the 3-day delay study 39 separate delays were recorded (Figure 5). In total, these 39 delays totalled 5.2 hours of the 25.5 SMH. The majority of these delays were associated with the "other" category, however only accounted for 1.4 of the 5.2 total hours of delays (Figure 6).

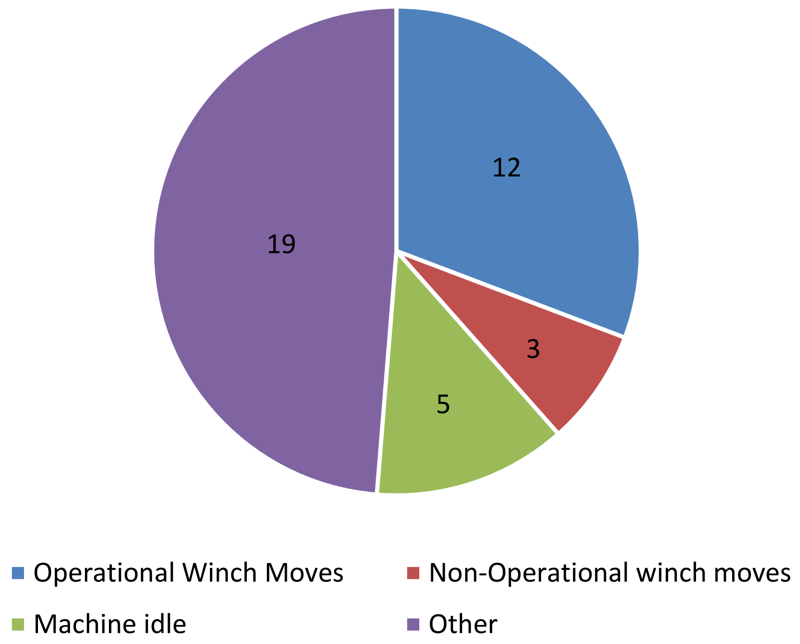


Figure 5: *Frequency of delays during the 3-day delay study.*

The most frequent cause for delay was operational winch moves. These delays occurred when the operator moves/adjusts the winch-assist to begin a new felling corridor, or unhooks the machine to walk it to a new operational position. Whilst these events are considered a delay, they are necessary in order to continue working productively. The length of time the winch-assist sat idle (not working) was 1.2 hours, across 5 separate events during the 3-day delay study. These delays included warming the machine up and attaching the ropes to the felling machine.

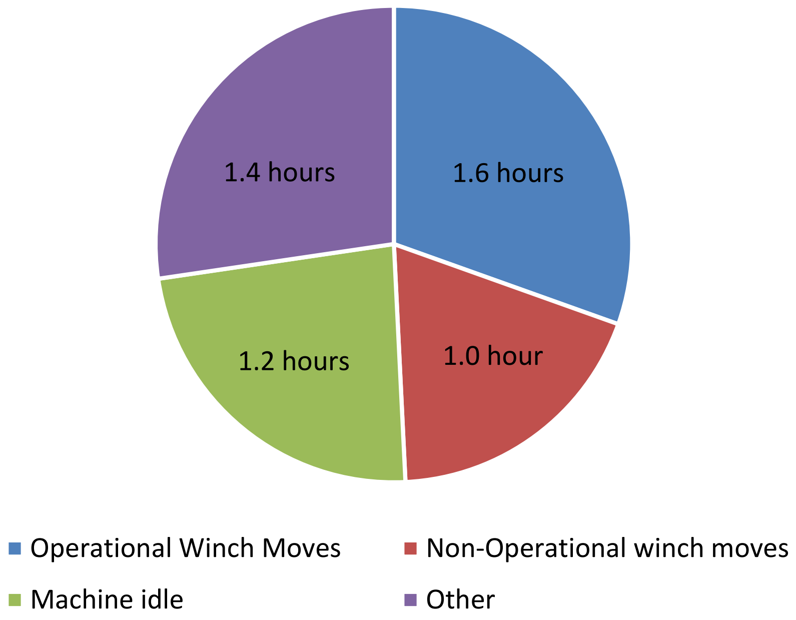


Figure 6: *Length of delays during the 3-day delay study (hours).*

The results of the 3-day delay study were averaged, providing a breakdown of the average 8.5 SMH work day for the delay study period (Figure 6). The largest proportion of time was used productively, which is the average utilisation rate in Table 6. Delays account for an average of 1.7 hours of the typical work day, represented by the four delay categories in Figure 7.

As the winch-assist was only used for half-days on the 10th and 12th of April, this significantly influenced the utilisation rate as seen in Table 6. The average time the winch-assist spent "Off" during these half days was 2.7 hours or 32% on average. In regards to Utilisation Rates 1 and 2, two utilisation rates have not been calculated for the delay study as the winch-assist was used during each day of the study. Therefore the utilisation rate of 47% concluded from the delay study can only be compared to Utilisation Rate 1 described in section 6.1.2.

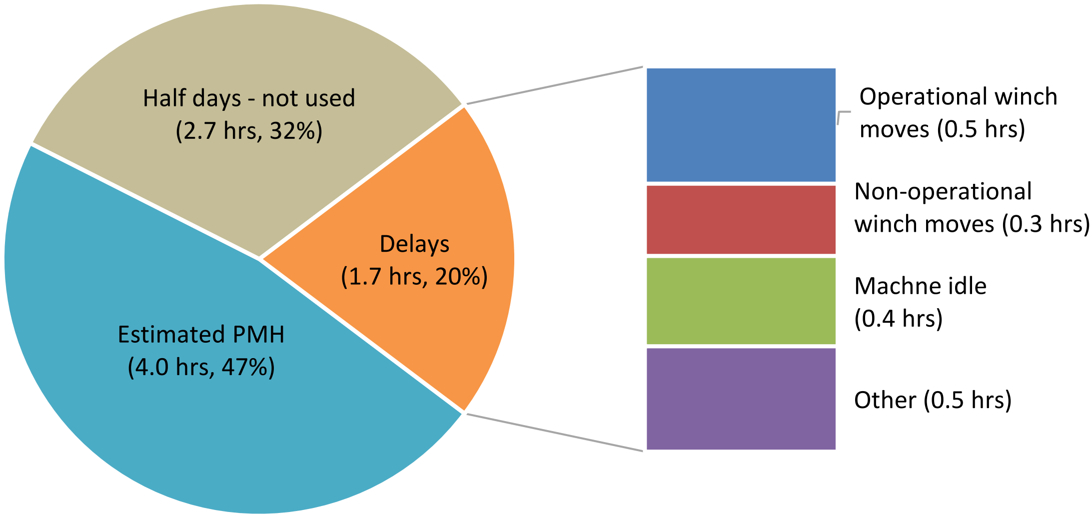


Figure 7: *Breakdown for the average work day (8.5 SMH) during the 3-day delay study.*

The difference between the delay study utilisation rate, and Utilisation Rate 1 is 13%. For this reason, the utilisation rate has also been calculated for the same three days as the delay study using the TeletracNavman GPS data. This comparison has been made to determine if there are differences between the two data collection methods, and identify factors that may influence the results.

Similar to Table 6, Table 7 below compares the utilisation rates as recorded by the 3-day delay study and GPS data for the 9th, 10th and 12th of April, 2018. Whilst the utilisation rates are all similar, the utilisation rate is lower each day, and on average, for the 3-day delay study. The difference in utilisation rates can be attributed to the increased accuracy of the detailed delay study. The detailed delay study method allows all delays (especially those <10 minutes) to be accurately recorded and identified. Despite there being an 8% difference in utilisation rates, the TeletracNavman GPS units remain a reliable system for accurately estimating the utilisation rate of winch-assist machines.

Table 7: *Comparison between the 3-day delay study and GPS derived utilisation rates.*

Day	GPS Utilisation Rate 1 (%)	Delay Study utilisation rate (%)
1	78	72
2	44	37
3	42	32
Average	55	47

As the delay study proved that not all delays could be captured by the GPS units, all days the winch-assist worked during the study period were manually reviewed. The purpose for manually reviewing the GPS data was to determine the inaccuracies of the GPS units, as well as provide the most accurate estimate of the true utilisation rate for the winch-assist machine. Using machine location data captured by the GPS units on both the felling machine and winch-assist, delays for each of the 4 categories were manually assessed using the TeletracNavman reporting software Director. Figure 8 highlights the proportion of delays that were unable to be captured by the GPS unit alone during the study period. Without manually reviewing the data, Utilisation Rates 1 and 2 are over-estimated by 10% and 8%, respectively.

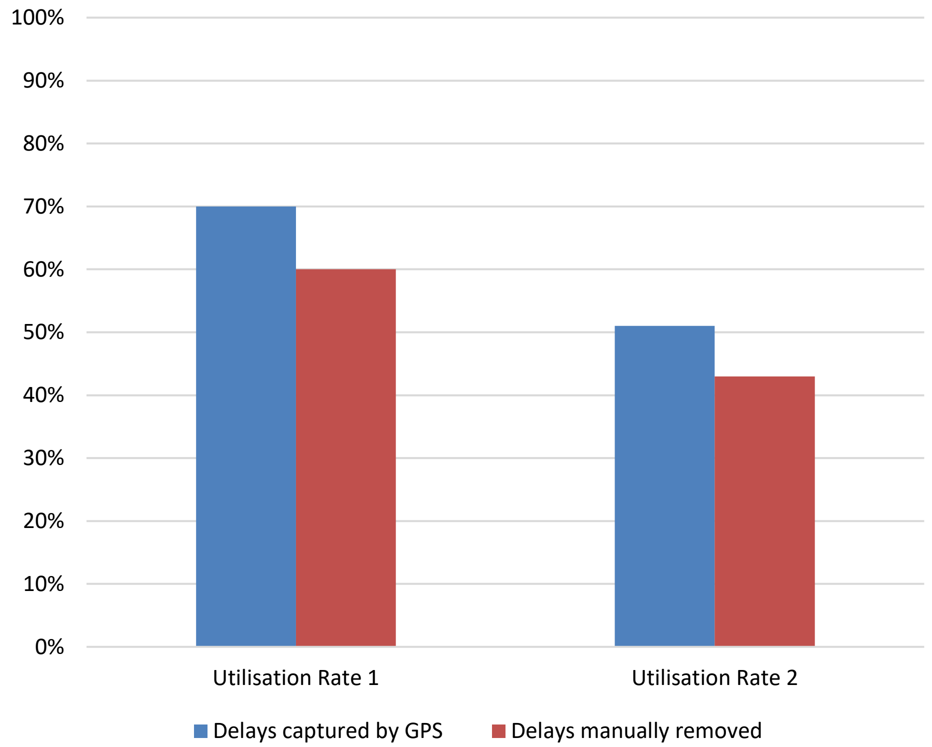


Figure 8: *Variation in reported utilisation rates determined by method used to account for delays.*

6.2.2 GPS (Director) Delays

As previously mentioned (also displayed in Table 7) the utilisation rates for the delay study and GPS units were varied during the 3-day study period. These differences occur as the detailed delay study was able to identify more frequent and often smaller delays than the GPS unit (Table 7). Despite the frequency of these delays, those that were unable to be captured by the GPS contributed to just 13 minutes across the 3-day study period. Table 8 outlines these differences, where the results varied by up to ±10 minutes on any given day, but overall for the 3 days the difference was only 8 minutes.

Table 8: *Comparison between GPS and actual data during the 3-day delay study period.*

	Total GPS Delay (min)	Total Measured Delay (min)	Δ (min)
Day 1	224	214	-10
Day 2	40	48	-8
Day 3	43	53	+10
Total	307	315	8

The GPS units captured all major (>10 min) delay events during the 3 day study period. Variation between observed and GPS data was due to short personal and operational delays that were not captured by the GPS units, but were observed during the 3-day delay study. The GPS unit on the felling machine was wired to the hydraulic lock-out which determined when the machine was working or idle. Therefore, during these short delays observed it can be assumed that the operator has not engaged the hydraulic lock-out; which is a plausible assumption as the operator remained in their machine during each of the recorded delays. This connection to the hydraulic lock-out (Appendix 2) is referred to as a “CoNex” connection; and is an additional add-on to the TeletracNavman GPS units.

Overall the delay result is satisfactory (± 10 min), whereby the difference between measured and GPS delay for the full day the winch-assist was used recorded was only 4%. During the two half days the winch-assist was used, only 48 - 53 minutes of delays were recorded each day. The difference between that recorded and observed, was -8 to +10 minutes; but as a percentage of recorded GPS delays equated to a 20% - 23% difference. As such, this system should not be considered accurate for short recording periods of less than two full days.

SMH for the 6 month study period were 1,046 based on 123, 8.5 hour work days. Of this period, the winch-assist was productive 43% of the time; Utilisation Rate 2. The winch-assist was not used for 35 whole days (298 hours, or 29%), and was also "Off" for the equivalent of 26 days as the sum non-used time during half-days. The remaining percentage of time during the study period were delays.

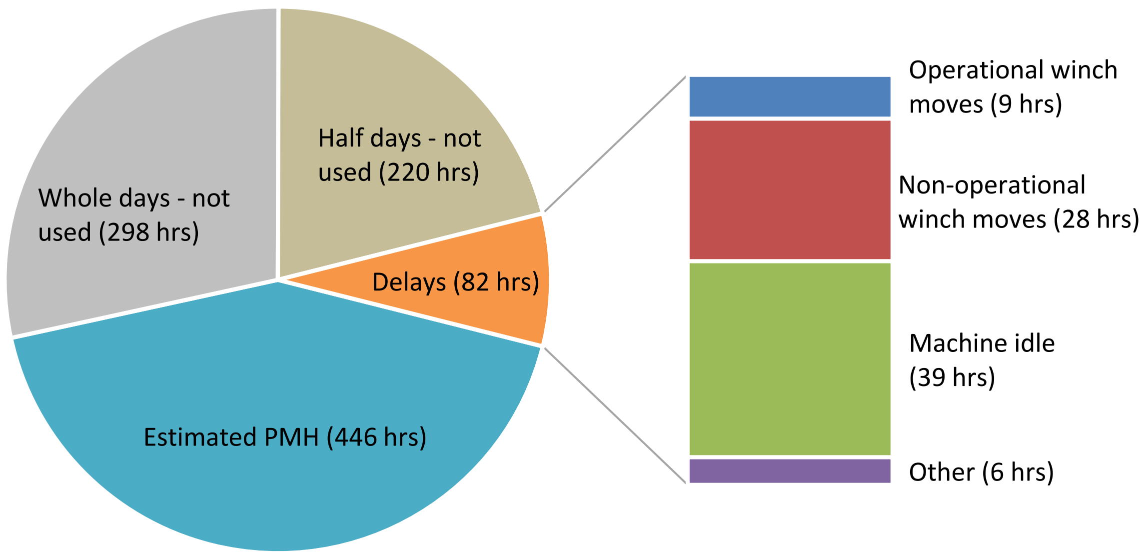


Figure 9: *Breakdown of winch-assist machine utilisation for the six month study period.*

6.3 Slope

Latitude and longitude data were captured by the GPS unit in the felling machine, and were manipulated to provide the slope the felling machine was operating at each one minute intervals when working with the winch-assist. The three slope classes in Figure 9 were specifically chosen based on current steep slope harvesting practices, and the EMS Tractionline manufacturer's specifications. Interestingly, when working with the winch-assist the felling machine spent 65% of the time operating on slopes up to 22 degrees, which are typically felled without the need for winch-assist. Although the majority of time was spent on slopes less than 22 degrees, it is possible that this would have been exceeded during the day, therefore justifying the use of the winch-assist. Slope alone does not dictate winch-assist use either, with soil type and weather conditions also influencing the use of the winch-assist machine. The average slope the felling machine operated on during the study period was 18 degrees, with a range of 0 - 46 degrees.

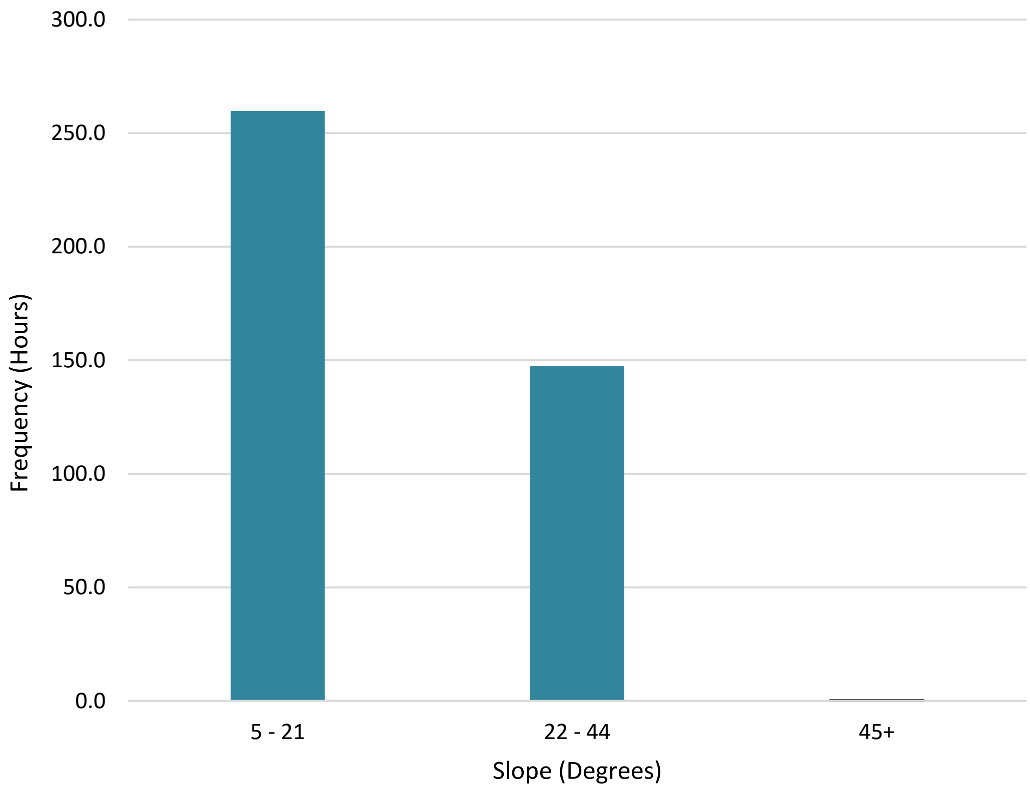


Figure 10: *Frequency of time felling machine spent operating in each slope class.*

6.4 Factors Influencing Utilisation Rate

TeletracNavman reporting software Director allows the user to manually review each day the winch-assist was used. With the ability to track machine movements and location at 1 minute intervals, as well as access to Google Earth, the following information was derived for the study period, for both the felling machine and winch-assist:

- Maximum distance felling machine was from winch-assist (Felling corridor, m)
- Area felled (ha/day)
- Number of sites the winch-assist operated from per day (Winch moves)

These three factors are summarised in Table 9, on a monthly basis for the length of the study period. These factors were analysed against Utilisation Rate 1, as factors that influence the utilisation rate can only occur when the winch-assist is operational.

Table 9: *Monthly summary of factors that may affect Utilisation Rate 1.*

Month	Average daily Utilisation Rate 1	Average winch moves per day	Average of daily maximum felling corridors (m)	Area Felled (ha/day)
February	57%	1	144	11.2
March	55%	3	128	10.9
April	61%	3	112	16.5
May	73%	2	159	7.8
June	56%	2	167	10.1
July	64%	2	184	12.2

The statics software RStudio was used to determine whether any of the factors individually or collectively influenced Utilisation Rate 1. Data was initially analysed on a per month basis. Of the three factors, only area was found to influence Utilisation Rate 1. However, as data was analysed on a monthly basis, there were too few data points (i.e. six) to be able to conclude that there was a statistically significant difference. Therefore, a new dataset was created to analyse the data on a daily basis for the study period.

When analysed on a daily basis, area felled per day was again the only factor that influenced Utilisation Rate 1. A model was derived to predict the utilisation rate of the winch-assist, based on the amount of variation in utilisation was affected by the area felled. As only one of the three factors was found to significantly influence the utilisation rate, the model below may only be practical to produce estimates of Utilisation Rate 1. The model does however serve as a tool to easily estimate utilisation rate based on one key variable, area felled per day (A), represented in hectares. The remaining variables in the equation are transformation variables, required to transform the result into Utilisation Rate 1 based on the analysis performed in RStudio.

$$Utilisation\ Rate\ 1\ (\%) = \left[\left(\left(\frac{A^{0.7}-1}{0.7}\right)\times 0.28 - 0.26\right)\times 1.43 + 1\right]^{(0.7)}$$

Figure 11 highlights the linear relationship between area felled per day and Utilisation Rate 1. The adjusted R^2 value for the relationship was 0.41, which implies that 41% of the variation in Utilisation Rate 1 is explained by the area felled each day. This value was statistically significant at a confidence interval of 0.05, with a p value of 1.51×10^{-11}. The R^2 value of 0.41 reiterates the point that whilst the model and equation stated above are imperfect, area felled per day does influence utilisation rate of the winch-assist machine.

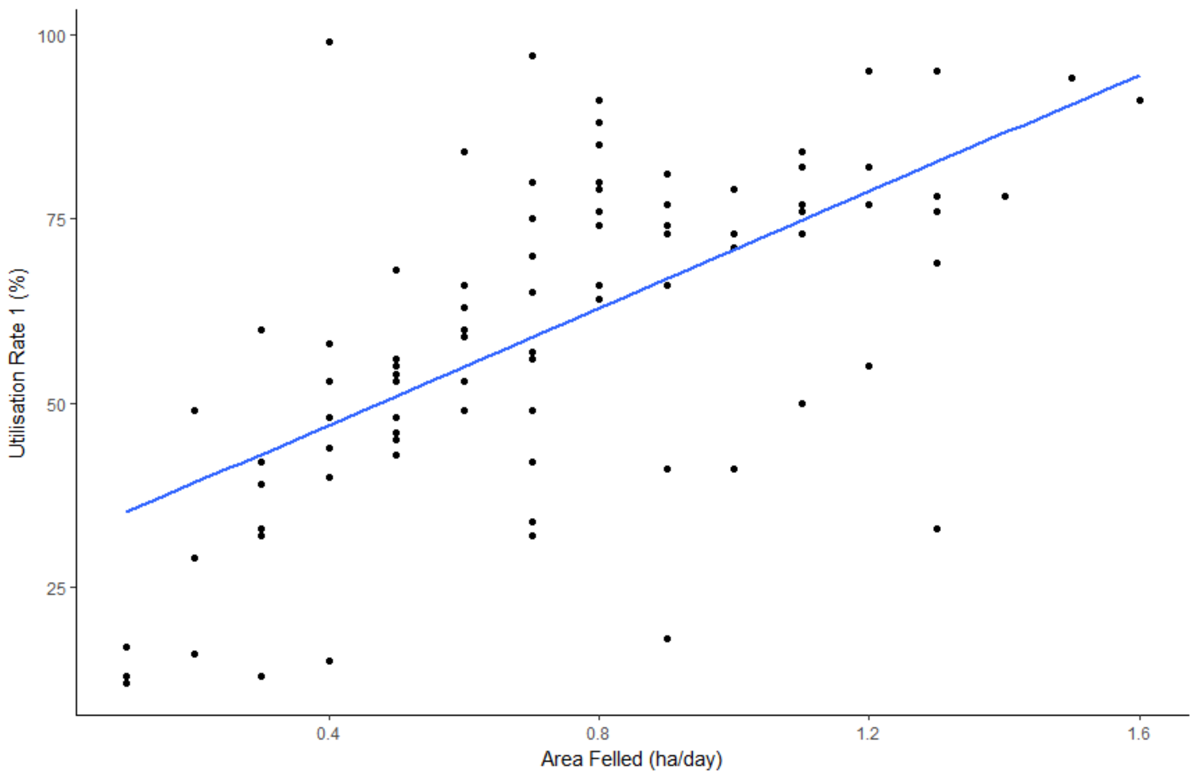


Figure 11: *Variation in linear relationship between area felled per day (ha) and Utilisation Rate 1 (%).*

7.0 Discussion

7.1 Global Positioning Systems

Throughout the length of the study period, the TeletracNavman QT200 GPS units proved that they were able to capture the required data automatically and accurately, without the costs and risks associated with an employee involved in the data collection process (Veal et al, 2001; Gallo et al, 2013). It was found from a detailed delay study that the units could not capture all of the delays that occur, other GPS units such as the MultiDAT overcome this issue with a user-based system. When a delay occurs, the operator uses a touchpad on the MultiDAT unit, manually informing the system of the reason for the delay. Whilst operator input could be a solution to overcoming the limitations in recognising delays with the TeletracNavman units, the system would rely on the operator's input and cooperation with the GPS recording system; potentially increasing their workload and removing the completely automated nature of the recording software.

7.2 Utilisation Rate

Utilisation rate was derived as the ratio of estimated productive machine hours (PMH) based on the machine "On" and "Off time and the delays that occurred each day, and scheduled machine hours (SMH) which were assumed to be 8.5 hours each working day (Holzleitner, Stampfer, & Visser, 2011). For this study, two utilisation rates were derived using this method. Utilisation Rate 1 was a function of the 88 days the winch-assist worked during the study period. Utilisation Rate 2 was a function of the total possible time the winch-assist could have worked, or the 123 days that the felling machine worked during the study period; the difference between the two being the 35 days that the winch-assist was not used at all.

As utilisation rates drive key management decisions (Miyata & Steinhilb, 1981), it was important to provide both Utilisation Rates 1 and 2 as just one or the other would be misleading. Utilisation Rate 1 was used to determine the factors that influenced utilisation, whereas Utilisation Rate 2 can be applied to the current day rate method the machine is paid on, as it represents every possible day during the study period regardless of whether it worked or not.

The results for Utilisation Rates 1 and 2 are similar to the few studies that have been published in regards to the utilisation of winch-assist machines. A study of a Falcon winch-assist machine in British Columbia claimed the utilisation was 71%. However, the authors suggested that the utilisation rate could range anywhere between 40% - 70% when working, consistent with the estimates of utilisation rates from this study, but more importantly directly comparable to how Utilisation Rate 1 was calculated for this study. Similarly, a survey of New Zealand forestry contractors found that the average utilisation rate of participant's winch-assist machines was 45% (Harrill, Reriti, & Visser, 2018), similar to the methodology and overall Utilisation Rate 2 of 43% that was derived from this study.

7.3 Delay Study

A detailed delay study was carried out in April with the aim of determining any inaccuracies associated with the GPS units, as well as provide the most accurate estimate of true PMH for the winch-assist machine. Whilst delays are traditionally categorised as personal, mechanical or operational (Spinelli & Visser, 2007), they have been categorised differently for this study. Data recorded during the delay study were recorded in one of the four categories stated below:

- Operational winch moves.
- Non-operational winch moves.
- Machine idle.
- Other.

The category "Machine idle" captured the time that the winch-assist was working, yet not moving during the study period. This category was required as it is known that downtime occurs in forestry operations due to machines sitting idle, however more importantly because although the GPS units capture all of the large delays (> 2 minutes) when they occur, we cannot determine as to why these occur. This same category was used during the 3-day delay study as periods of machine idle were recorded by the observer.

Spinelli & Visser, (2007) highlighted that delays are recognized as being one of the major factors that limit productivity in most operations. Whilst delays did affect the productive machine hours of the winch-assist, it was both planning (days the winch-assist was not used) and machine idle that had the most significant impact on the utilisation rates that were derived from this study. Improved planning in regards to allocation of harvest settings and the addition of a second felling machine into the current system could potentially increase Utilisation Rate 2. Improved planning of operational and non-operational winch-assist moves may also increase Utilisation Rate 1 (Harrill, Reriti, & Visser, 2018).

The delay study provided the opportunity to compare the accuracy of automated recording methods (GPS units) and the traditional time study/delay study method. It was previously thought that automated systems can accurately capture both major and minor delays in an operation (Gallo et al, 2013; Hejazian et al, 2013). Results from the 3-day delay study highlighted that the TeletracNavman QT200 GPS units were unable to capture all minor delays that occurred, however all major delays were successfully captured by the GPS units. Both automated and traditional methods for capturing such data have their strengths and weaknesses. In regards to the QT200 GPS units, if smaller delays can be captured using automated GPS technology, the estimate of the utilisation rate will be closer to that of the true value.

7.4 Benefits from this study

Pan Pac Forest Products are currently in a trail period with TeletracNavman, with the potential to increase the number of QT200 GPS units into a range of forest machines. The results from this study provide key information in regards to how these units perform, what they can and can't capture, provide insight into how the reporting software functions and can be manipulated and most importantly outlines the steps and process used to derive the utilisation rate for a winch-assist machine.

An estimation of a utilisation rate for winch-assist machines provides the following benefits to the forest industry, not only in New Zealand but also worldwide. The following benefits have been concluded from this study:

- Contractors looking to purchase their first winch-assist will have an idea of how often these machines are currently used, and how much they could expect to use a winch-assist if they were to purchase one.

- Utilisation rates may dictate whether specific add-ons available for winch-assist machines are added during the fit-out (E.g. quick hitch to utilise the machine when it is not being used for its primary function).
- A key metric in deriving accurate and fair costing for these machines.
- Focussing on the key factors that have been identified to influence utilisation, to improve the utilisation rate of both new and current winch-assist machines in service.
- This study highlighted improvements for TeletracNavman's reporting Software Director, allowing the company to further refine their product.
- The relationship between Pan Pac Forest Products and TeletracNavman has strengthened, with both parties benefitting from an in-depth study using TeletracNavman's technology in Pan Pac's Contractor's forest machines.

The aim of this study was to determine the utilisation rate for a Tractionline winch-assist machine, and identify the factors that influence utilisation rate. As well as benefitting Pan Pac Forest Products, it is hoped that the work conducted from this study will prove useful for contractors and mangers alike, as mechanised felling systems and winch-assist machines become more common within the forest industry globally.

7.5 Limitations

The aim of this study was to determine the utilisation rate of a winch-assist machine and factors that affected this rate. However, the study only analysed one machine. There are multiple different winch-assist machines available commercially in New Zealand, as well as a number of unique one-off winch-assist machines developed by contractors throughout the country too. Future studies may yield more accurate results if they were to analyse multiple machines.

As the GPS units measured machine use for the winch-assist and felling machines for the entire study period, it can be concluded that the major factors that influenced the utilisation rate were the frequency that the machine was used, and the two most frequent causes of delays (i.e. non-operational winch moves and machine idle). Just one of the three potential factors was found to significantly influence Utilisation Rate 1, and this one factor only explained 41% of the variation in these results.

Although the 3-day delay study was of sufficient length to capture the information that was required for this study, a delay study that was at least two working weeks long, across a number of different sites would have provided a more comprehensive understanding of winch-assist use. An increased delay study length may have also provided the opportunity to determine more factors that may affect winch-assist utilisation, potentially increasing the accuracy of the model that currently estimates Utilisation Rate 1 based on the area felled per day.

Whilst the TeletracNavman QT200 GPS units provide an adequate estimation of winch-assist utilisation, further manual analysis of the data was required. This manual analysis was a form of sensitivity analysis, ultimately determining how effective the GPS units are at capturing all of the delays that occur. However as described, the results are not completely accurate from the 3-day delay study results. Without this analysis, utilisation rates would have been reported 10% and 8% higher than they actually were for Utilisation Rates 1 and 2, respectively.

This is the first time TeletracNavman QT200 GPS units have been studied extensively, to estimate the utilisation rate of heavy equipment and determine factors that influence utilisation. Ongoing development between Pan Pac and TeletracNavman hopes to refine the reporting software and interfaces, to remove the need for the data to be reviewed manually. These changes will remove the need to manually review data, further increasing the ability, accuracy and efficiency of this technology. These developments should also aim to improve the ability of the GPS units to capture smaller delays.

7.6 Future Research

Based on the conclusions and limitations of this study, if a similar study was to be replicated or conducted, it is recommended that the following points are taken into consideration:

- Studies of more than one winch-assist machine/felling system.
- Increased length, or more detailed delay studies.
- Exploring more factors that may affect utilisation.
- Estimating utilisation using different GPS software.
- Refined GPS reporting software to remove the need for manually reviewing data.

8.0 Conclusion

This study aimed to answer three questions regarding: the ability of GPS systems to estimate the utilisation rate of winch-assist machines, what the utilisation rate of these machines are, as well as identifying the factors that influence utilisation rate. Machine “On” and “Off” data alone were not enough to derive an accurate estimate for utilisation rates, and were required to be further analysed manually. The 3-day delay study confirmed that whilst the GPS units could accurately capture all of the major delays that occurred, some minor delays were not captured. Despite these complications, the TeletracNavman GPS units can provide an adequate estimation of the utilisation rate for winch-assist machines; so long as the data is reviewed manually at this point in time.

Two utilisation rates were derived for the winch-assist machine. Utilisation Rate 1 was derived for only the time the winch-assist and felling machines worked together during the study period. This utilisation rate was derived as factors that affect utilisation only occur when the machine is being used, which relates to one of the main objectives of this study. Utilisation Rate 1 of the winch-assist machine was 60%. Utilisation Rate 2 was derived on the basis of the current day-rate payment method of the winch-assist machine. Utilisation Rate 2 of the winch-assist machine for the entire study period was 43%.

The utilisation of the winch-assist machine was found to be influenced by three main factors. If any of these three factors were to be improved, an increase in the utilisation rate would be expected. The factor that significantly influenced Utilisation Rate 2 was the frequency of the days that the winch-assist was not used. If the days the winch-assist is not used can be reduced, not only will utilisation be higher, but these areas of steep and often difficult terrain will not be required to be felled motor-manually. The three factors that influenced the utilisation rate of the winch-assist machine were:

- Frequency the winch-assist wasn’t used (35/123 days)
- Area felled/day
- Delays
    - Non-operational winch moves
    - Machine Idle

9.0 References

Amishev & Dyson. (2018). *Falcon Forestry Equipment (FFE) winch-assist harvetsing system.* Vancouver, British Columbia: FPInnovations.

Amishev, D. (2011). *Steep Slope Feller Bunche: A Feasibility Study.* Rotorua, New Zealand: Future Forests Research.

Arlinger, J., & Moller, J. (2014). Time studies based on automatic data collection. *5th Forestry Engineering Conference 2014.* Gerardmer, France: Skogforsk, The Forestry Research Institute of Sweden.

Bergstrand, K. G. (1991). Planning and Analysis of Forestry Operation Studies. *Skogsarberten Bulletin*.

Dyson, P. (2017). *Assessments of a Winch-Assisted John Deere Harvester and Forwarder.* FPInnovations, Technical Report no. 57.

Forest Growers Research. (2017). *Steepland Harvesting Programme: Final Programme Report.* Ministry for Primary Industries.

Gallo, R., Grigolato, S., Cavalli, R., & Mazzetto, F. (2013). GNSS - based operational monitoring devices for forest logging operation chains. *Journal of Agricultural Engineering*, 140 - 144.

Ghaffaryan, M. (2015). Evaluating the machine utilisation rate of harvester and forwarder using on-board computers in Southern Tasmania (Australia). *Journal of Forest Science*, 277 - 281.

Harrill, H., Reriti, B., & Visser, R. (2018). Measuring the utilisation rate of winch-assist machines. *Forest Growers Research*, 7.

Hejazian, M., Hosseiini, S., Lotfalian, M., & Ahmadikoolaei, P. (2013). Possibility of global positioning system (GPS) application for time studies in forest machinery. *European Journal of Experimental Biology*, 93 - 98.

Holzleitner, F., Stampfer, K., & Visser, R. (2011). Utilization Rates and Cost Factors in Timber Harvesting Based on Long-term Machine Data. *Croatian Journal of Forest Engineering*, 501 - 508.

Hossain, M. M. (1998). *Young stand thinning in western Oregon: cost comparison of harvetsing alternatives and comparison of time study techniques.* Corvallis: Forest Engineerin gDepartment, Oregon State University.

Kryzanowski, T. (2018). FPDat Transport: better tracking wood transport operations. *Logging & Sawmilling Journal*, 53.

Laforest. (2012). *A case study of the implimentation and evaluation of on-board computers in forest operations in northern Ontario.* Thunder Bay, Ontario, Canada: Faculty of Natural Resources Management, Lakehead University.

Laforest, S., & Pulkki, R. (2014). On board computers in forest operations in northern Ontario, Canada. *Precision Forestry Symposium*, 72 - 74.

Magagnotti, N., & Spinelli, R. (2012). *Good practice guidelines for biomass production studies.* Italy: CNR IVALSA.

McDonald, T. (1999). *Time Study of Harvesting Equipment Using GPS-Derived Positional Data.* Auburn, AL, USA: USDA Forest Service.

McDonald, T. P., & Fulton, J. (2005). Automated time study of skidders using global positioning system data. *Computers and Electronics in Agriculture*, 19 - 37.

Miyata, E., & Steinhilb, H. (1981). *Logging System Cost Analysis.* Minnesota: Forest Service - U.S. Department of Agriculture .

Olsen , E., Hossain, M., & Miller, M. (1998). *Statistical Comparison of Methods Used in Harvesting Work Studies.* Forest Research Labratory, Oregan State University.

Riddle, A. (1995). Mechanisation of logging operations in New Zealand. *N.Z. FORESTRY* (pp. 17 - 21). New Zealand Journal of Fiorestry.

Sigrist, P., Coppin, P., & Hermy, M. (1999). *Impact of forest canopy on quality and accuracy of GPS measurements.* 20:18, 3595-3610: International Journal of Remote Sensing.

Spinelli, R., & Visser, R. (2007). Analysing and Estimating Delays in Harvester Operations. *International Journal of Forest Engineering*, 36 - 41.

Strandgard, M., & Mitchell, R. (2015). Automated Time Study of Forwarders using GPS and a vibration sensor. *Croatian Journal of Forestry Engineering*, 175 - 184.

Strandgard. (2011). *Application of MultiDAT onboard computers for management of native forest operations.* Hobart: CRC for Forestry Bulletin.

Taylor, S., McDonald, T., Veal, M., & Grift, T. (2001). *Using GPS to Evaluate Productivity and Performance of Forest Machine Systems.* First International Precision Forestry Symposium.

TelertracNavman. (2018, July 20). Retrieved from https://www.teletracnavman.co.nz/telematics-definitions/what-is-telematics

TeletracNavman. (2018, August 11). *Teletrac Navman.* Retrieved from 2018 Teletrac Navman Group: https://www.teletracnavman.co.nz/company/about-teletrac-navman

Veal, M., Taylor, S., McDonald, T., McLemore, D., & Dunn, M. (2001). Accuracy of Tracking Forestry Machines with GPS. *American Society of Agricultural Engineers*, 1903 - 1911.

Visser. (2017). *Benchmarking Harvesting Cost and Productivity.* Rotorua, NZ: Future Forests Research Ltd: Harvesting Technical Note HTN09-08 2017.

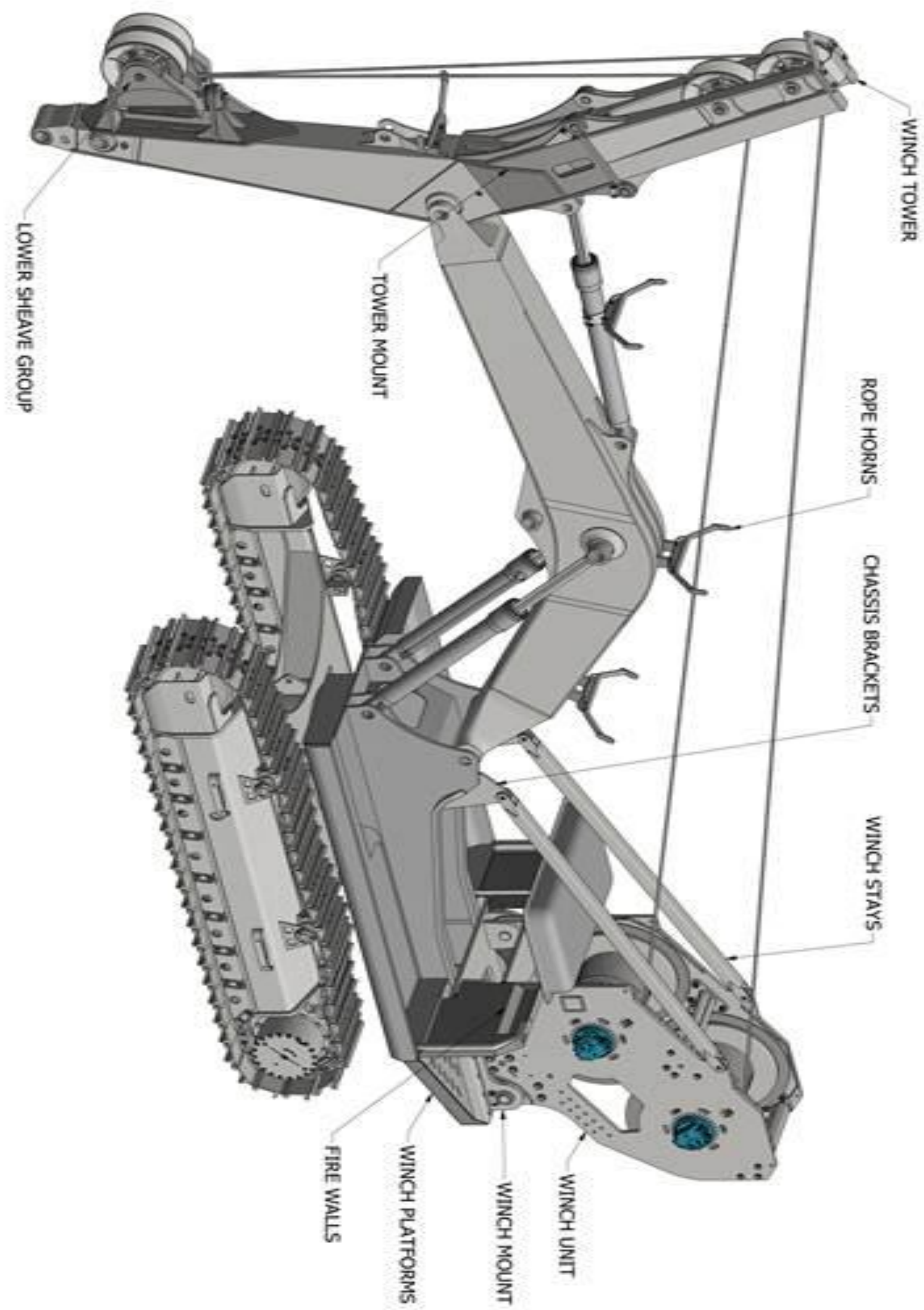
Visser. (2018). *Benchmarking Harvesting Cost and Productivity - 2017 Update.* Forest Gowers Research, Rotorua, New Zealand: Harvesting Technical Note HTN10-02 2018.

Visser, R., & Stampfer, K. (2015). Expanding Ground-based Harvesting onto Steep Terrain: A Review. *Croatioan Journal of Forest Engineering*, 321 - 331.

Visser, Raymond & Harrill. (2014). Mechanising steep terrain harvesting operations. *New Zealand Journal of Forestry*, 3 - 8.

10.0 Appendices

Appendix 1 – Tractionline winch-assist diagram.



Appendix 2 – Excavator Hydraulic lock-out.

Highlighted in the red circle is the hydraulic lock-out lever on a CAT 552B self-levelling felling machine that was observed during this study. A CoNex connection was applied to this lever, which allowed the GPS unit in the felling machine to distinguish between work and idle, which could then be aligned with the use of the winch-assist machine.

Source: https://s7d2.scene7.com/is/content/Caterpillar/C742693

Appendix 3 – Delay Study Template.

Date: ____________ Slope: ____________

Machine “ON” & “OFF” times: ______am _______pm

Min Winch out: __________ Max Winch out: ___________

Key:

OP: Operational
M: Mechanical
P: Personal
W: Moving Winch Assist

Reason for delay	Delay <10 min	Delay >10 min	Notes & Slope