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Development of a Semi-Automated Hauler and Grapple Carriage

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EXECUTIVE SUMMARY

According to the New Zealand Forest Owners Association (FOA), over 60% of production forests in New Zealand are situated on steep terrain requiring cable systems for harvesting. Traditional cable systems are manually intensive with manual felling using chainsaws and breaking out using strops to attach stems for extraction, both tasks being physically demanding. The accident and injury rate for this type of work is high in proportion to other tasks and worker compensation claims are often at the upper end of the spectrum.

Over recent years, high-cost swing yarder systems using mechanical grapples have been introduced to improve the performance of the steep country operations and mitigate the risk of accidents, but these systems have terrain and haul distance limitations. The concept of using mid-range 70' tower skyline machines and motorised grapple carriage options was championed by a progressive engineering firm in Whangarei and a proposal was submitted to Forest Growers Research (FGR), for joint venture funding in 2018.

With support from FGR, Rosewarne & May Ltd of Whangarei (R&M) refurbished a second-hand Thunderbird TTY 70 hauler and designed and built an automated hauler control system and a new concept grapple carriage. The original plan was to improve safety by automating elements of the extraction cycle and prolonging rope life by eliminating shock loading. Embedded in the proposal was improving the ergonomic environment of the operator by redesigning the operator cab to make it more comfortable and reduce operator workload.

The drum set on the hauler was refurbished and the clutch and brake for the skyline drum replaced with hydraulic motors, powered by the existing hydraulic system. A Controller Area Network (CAN bus) system was installed to control all hauler functions. This meant that skyline tension could be set to maintain below safe working load of the skyline and maximise payload of the skyline. The operator's cab was re-aligned to improve vision of the drop zone in the landing chute and the air control levers were replaced with electronic joystick control.

The grapple carriage design was based around the grapple mounted on a hanging bracket, suspended from a central shaft above the carriage containing the motor and electronics. Any shock loading or sudden impact with obstacles on the ground would be transmitted directly through the hanging bracket and sheaves along the skyline, not through the body of the carriage. Modern camera technology was applied through the CAN bus communication system to give the operator clear vision of the grapple functions when accumulating a load of tree stems.

The original plan to automate all hauler functions has been revised by Rosewarne & May Ltd to control of the skyline drum only on the first prototype. It was felt that full automation may not yield the productivity increases expected initially. The project has been divided into two phases, the first to measure the reduction in operator stress and equipment damage and its effect on production and costs. The second phase will investigate the effects of further automation once initial trials have been completed.

Initial commissioning trials showed that modifications to the grapple and hauler functions were required to complete phase one of the project. Some components of the grapple carriage need further refinement to improve performance and reliability. This report on the development project covers progress in phase one of the project.

A brief production study was completed in March 2022 on the semi-automated hauler and grapple carriage to benchmark performance of the system. Results of this study showed that the system was capable of producing 33 cubic metres (m^3) per productive machine hour, but delays of up to 32% of scheduled machine hours affected overall performance. A full production study to compare the prototype system with a conventional mechanical winch driven hauler will be undertaken once phase one of the project is completed.

BACKGROUND

Automation of cable harvesting functions dates as far back as 1958 when standing skyline cranes used radio-controlled carriages, (Pearce & Stenzel, 1972). In 1967 a radio-controlled grapple was used on an Ecologger skyline hauler when stumpage and labour rates increased significantly, and the US logging industry was struggling to find workers. The drive to improve efficiency came from a 295% increase in log prices over a ten-year period between 1963 and 1973, (Binkley & Studier, 1974). This resulted in the development of the Skycar carriage which had the capacity to laterally yard up to 75 metres away from the skyline.

A Canadian company, Forestral Automation Ltd developed a remote spotting system for cable hauler carriages which was trialed on two haulers, an Ecologger skyline machine and a Skagit GT5. Two separate studies were conducted on this system, one by Forestral themselves and the other by Weyerhaeuser in Washington. Results showed that, in both studies, greater productivity was achieved with the remote spotting system, but mechanical reliability let it down and Forestral eventually went out of business, (Christensen, 1978).

With the significant planting regimes on steep country in the 1970's and 80's, New Zealand's cable logging capacity increased exponentially as these forests grew into maturity in the early 2000's. A study by University of Canterbury staff, (Visser & Harrill, 2017), showed that the number of haulers had increased from around 30 in 1980, to over 300 in 2012. Of those, 67% were tower haulers, 30% were swing yarders and 3% were excavator base machines fitted with after-market hydraulically powered drum sets. Many of these haulers were second hand, ex Pacific-Northwest machines with the Thunderbird TMY 70 and Madill 071 models being the most popular (Figure 1).

Figure 1: The Thunderbird 70' tower machine was one of the most popular model haulers in New Zealand cable harvesting operations in a 2012 survey.

Hydrostatic drive for cable haulers was trialed in the late 1970's with the development of the Lotus experimental hauler, manufactured by Lotus Enterprises Ltd, New Zealand, (McConchie 1979). Three different models were produced, ranging from a Series 1, a three drum, truck-mounted hauler for extraction thinning, (Prebble 1982), to the Series 3, skidder-mounted skyline hauler with the capacity to operate in second crop radiata clearfell (Simpson 1982). While the unreliability of hydraulic componentry at the time eventually lead to the demise of the brand, five mid-sized, truck-mounted haulers were exported: two machines to Jamaica, (Simpson and Prebble, 1982), and three to Sabah in 1989. A Series 4, rubber-tyred carrier mounted skyline hauler was also manufactured in the late 1980's and it worked in Taranaki forests for a number of years after the research project had concluded.

In 2014, a Rotorua based firm, Active Equipment Ltd, introduced a new concept with their Active 70 hauler which was a track-mounted, leaning tower hauler, paired with a Bowman Skycar carriage, Campbell, *et al.,*2016). This hauler had a 21m tower with built in tension monitoring and GPS tracking of the carriage using the ACDAT system, (recording carriage movements and issuing visual alerts). A key focus of this development was to improve the ergonomic environment for the hauler operator.

Remote control of hauler functions was studied in Germany using two Koller yarders, a 507 model and a 602h model, both with Koller MSK3 carriages, (Campbell, 2016). These machines offered the option of dual control where the breaker out controlled carriage movement at the break-out site and the processor operator controlled the carriage functions at the landing. Travel loaded and unloaded, were automated. In 2014 a Koller 602h was trialed in New Zealand forests, (Evanson *et al.,*2015).

Studies of a Valentini V850 hauler with a Hochleitner Bergwald 4000 3 tonne capacity self-clamping carriage in Italy compared manual operation with automated settings using the auto path programming and showed that the automated system was more cost effective over shorter extraction distances, >200m, (Spinelli *et al*., 2020). It is anticipated that operator learning times can be significantly reduced with increased levels of automation in cable hauler operations.

Increasing productivity and eliminating the use of manual breaking out in cable hauler operations was one of the key objectives in the Steepland Harvesting Primary Growth Partnership (PGP) programme co-funded by Future Forests Research (now FGR) and the Ministry for Primary Industries (MPI). Mechanising functions in cable harvesting operations was one of the programme goals that has been carried over into the new Automation and Robotics PGP programme.

The objectives of the Steepland Harvesting PGP to increase productivity and reduce hazards were achieved through increasing the use of motorised grapple carriages to eliminate the manual tasks of breaking out and unhooking in New Zealand cable hauler operations. A 2011 survey showed that less than 25% of crews had used them over the previous five years (Figure 2) and only 10% of these operations operated a grapple.

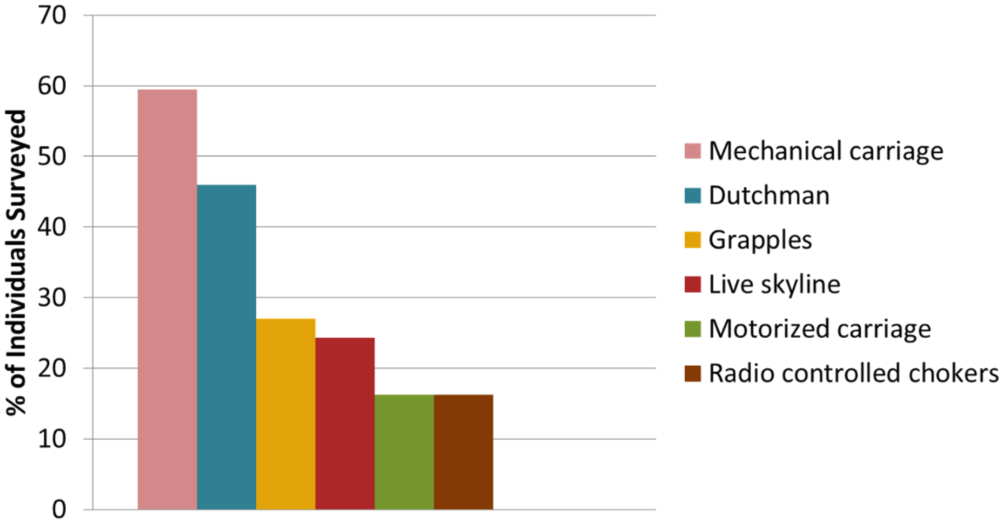

Figure 2: Cable systems in use in 2011

The main barriers to their use were:

- Primarily limited to swing yarders (only about a third of the hauler population at the time).
- Capital cost.
- Risk of damage (from hitting the ground).
- The need for a skilled operator and the resulting long learning curve.
- A lack of familiarity with grapple systems.
- Preference for shorter haul distances (due to requirement for good visibility by the operator).
- Smaller payload than choker rigging systems (unless wood was bunched).

Another factor limiting grapple use was the need for a live skyline to raise and lower it in the loading and unloading phases of the extraction cycle. While cycle times were generally quicker with grapples, payloads were lower (restricted to one to two stems which was well under the normal capability of the system), unless the wood could be bunched prior to extraction. Bunching stems prior to, or as part of, the extraction cycle improves payload, but it requires a feller buncher or a separate bunching machine and is very dependent of machine access. Lateral yarding with grapple systems tended to be limited to the reach of the swing yarder.

Solutions to these issues were seen as:

- Developing a grapple that operates on a tower hauler
- Risk of damage reduced by installing ground proximity sensing and a collision avoidance system
- Grapple yarder operator skills assisted by conversion to joystick hauler controls
- Greater skyline control achieved through hydraulic control of skyline
- Camera systems to provide greater visibility for the yarder operator
- Improved payloads through bunching of felled wood.

INTRODUCTION

With increasing labour rates and a compelling urge to improve safety in cable logging operations after the Independent Forestry Safety Review, (Adams *et al*., 2014), Lars Rosewarne, the managing director of Rosewarne Cable Loggers Ltd, (RCL), and director of Rosewarne & May Ltd (R&M) took a serious look at available options to improve the lot of workers in his operations. The high cost of equipment, coupled with the type of terrain and length of slopes, ruled out the option of a swing yarder with mechanical grapple for many of the blocks RCL had coming up in future. This prompted Lars Rosewarne to investigate ways of getting more out of the tower haulers that had served the business so well for so many years. In consultation with Iain May, co-director of R&M, a plan to refurbish used tower haulers was proposed.

Rosewarne & May Ltd was originally a workshop that Lars Rosewarne had set up to service his forest harvesting operations, and it already had a history of bringing innovative ideas into the forest industry with the successful development and marketing of the remote operated bulldozer, (ROB) for winch assisted harvesting. The company started to explore the option of automating functions on existing mobile haulers to facilitate the use of hydraulic grapple carriages, which had recently established a foothold in New Zealand cable operations. Lars Rosewarne wanted a machine that could log over a range of settings, including some with long extraction distances, but still be nimble enough to move quickly between landing locations to facilitate grapple use. The leaning tower mobile tracked haulers, (of which nearly 30% of NZ’s cable operations consisted), emerged as the obvious choice. These machines, with 16 – 21m tower heights and either rubber or track undercarriages, provided the ideal platform for this concept, (Prebble 1989a, 1989b).

In 2018, FGR became involved in the project and collaborated with R&M, MPI, Hancock Forest Management, (now Manulife Forest Management) and Rayonier Matariki Forests, to partner in the funding and development of a semi-automated motorised grapple carriage and tower hauler control system. A proposal was put to the stakeholders in September 2018 and their first meeting was held in November 2018.

Project objectives included:

- Auto inhaul, controlling skyline tension and ground clearance.
- Auto stop at the landing edge and lowering of the skyline to release the stems.
- Automatic carriage return to last break out point.
- Automatic lowering of the skyline and positioning of the grapple.

The technologies involved to achieve these objectives relied upon range sensing, electronic control systems, data-processing, and software development. The main benefits were seen as:

1. Improving safety by removing the hazard of breaker outs working under the rigging.
2. Reducing damage occurring from over-loading the system or high impact collisions.
3. Increasing productivity by more efficient use of human resources.
4. Reducing operator workload by replacing repetitive tasks with evolving technology.
5. Attracting different worker demographics to ease recruitment issues and aid staff retention.

A detailed workplan, consisting of milestones and a budget was prepared by R&M and FGR. The design and build of the new Semi-automated Grapple and Hauler Control prototype had a budget of $1.125 million, that comprised:

- Purchase of the hauler components and spare parts
- Design and build of the grapple carriage and hauler cab
- Initial testing.

The contribution of the industry partners was 60%: 20% from the two forestry companies, 20% from FGR (funded by the Forest Growers Levy Trust) and 20% from R&M as in-kind contribution. The balance of the project budget (40%) was funded by MPI through the Primary Growth Partnership. A Services Agreement between Forest Growers Research Ltd and R&M was signed by all the major stakeholders in September 2019.

A further $193,000 of direct costs (plus $135,000 in kind contributions) were budgeted for modifications, field trials, industry field demonstration, project management and commercialisation (Table 1).

Table 1: Project Budget and Actual Expenditure (to June 2022).

Year	Budget			Actual		
	Direct	**In Kind**	**Total**	**Direct**	**In Kind**	**Total**
2018/19	$0	$0	$0	$0	$0	$0
2019/20	$900,166	$225,041	$1,125,207	$901,295	$225,041	$1,126,336
2020/21	$98,536	$50,000	$148,536	$8,894	$342,697	$351,591
2021/22	$94,250	$85,000	$179,250	$57,469	$39,114	$96,583
Total	**$1,092,952**	**$360,041**	**$1,452,993**	**$967,658**	**$606,852**	**$1,574,510**

FROM CONCEPT TO DESIGN

Iain May started researching potential drive combinations to get the best performance out of these haulers. While the sensitivity and control of hydrostatic power had obvious benefits, the restricted line speed and inability to readily free wheel for gravity return systems meant that it wasn't the ideal powertrain for all hauler functions. It very quickly became apparent that a combination of hydraulic drive of the skyline drum with mechanical drive to the rest of the working drums was the ideal solution. This would give the best of both worlds and most of the leaning tower machines had plenty of hydraulic capacity, which lay idle, (unused), during extraction cycles.

Basic plans were drawn up in December 2018 and the Initial design was completed in January 2019. Elements of R&M's existing IP were utilised in the development and that local expertise returned significant benefits when it came to modifying the design and quickly adapting to changes that were required as the build progressed. R&M wanted to produce a quality product which would not only stand up to the rigors of New Zealand harvesting conditions, but also meet the requirements of the international ISO standard 1809006 for machine certification.

R&M committed to developing the automated hauler conversion to provide contractors with a solution to the opportunity cost of lost production while their hauler was being refurbished and fitted with the automation functions. It was proposed that the prototype hauler with new control system and integrated grapple carriage would be owned by R&M Ltd and leased out to clients while their machines were being retrofitted. In this way contractors and crews could get familiar with the concept and learn how to operate the hauler and carriage before their own machine arrived.

Lars Rosewarne preferred a track mounted hauler because they were more portable than rubber-tyred machines when maneuvering in the cutover or on low quality spur roads. The 21m tall tower provided good deflection and the hauler could be moved with the tower up if it was telescoped down to 15m. The 70' Thunderbird brand of haulers were the most popular mid-sized tower hauler in New Zealand, so the tracked TTY 70 model became the obvious choice for this conversion.

Improving the operator's environment was one of the most challenging projects. It was decided to install a complete new cab with joystick controls and an interactive screen which would create a comfortable, low stress working position and all the information required for the operator to make informed decisions. It was decided to re-align the cab to face directly into the drop zone in the chute where the drags were being landed which in turn, would improve the ergonomics of the workstation.

The introduction of CAN-bus technology created the opportunity to open up a whole new concept with a modular communication network using tiny microcomputers to monitor all hauler functions, such as; (engine management, hydraulics, the air control system and all the sensors). The CAN Bus network operates like a telephone exchange using just two wires to send all the data and live camera images back to the central processing unit, (CPU), mounted under the cab of the hauler. Collecting this information enables the CPU to develop a "memory" which will be invaluable when automating functions in the future.

One of the drawbacks with the current range of grapple carriages is having the grapple attached to the underside of the carriage, which means any impact forces from hitting objects are transmitted through the carriage and the engine. Having experienced this exact problem as a contractor Lars knew this would be a key element to the success of the carriage. With the grapple isolated from the motor unit, any impact forces are transmitted through the shaft directly to the ropes, insulating the engine from this shock loading.
A similar concept has been developed by Summit Attachments and Machinery Ltd in the U.S in their SG range of grapple carriages (Figure 3). Both companies are progressing down similar lines for a solution for these carriages.

Summit Attachments and Machinery Grapple Carriage

Summit offers three motorized grapple carriages — the SG80, SG100, and SG160. The three grapple sizes available are 80”, 100”, and 160” and are powered by heavy-duty diesel engines.

The 80” and 100” grapple carriages are powered by an air cooled Hatz 21hp 2-cylinder diesel engine and utilize the same body.

All feature joystick style controls in open, close, and rotate; grapple strength and holding power to grab and securely hold logs; full 360-degree rotation; and exclusive swing arm design for increased grapple mobility and accuracy. An HD Camera system allows precision operation when retrieving logs, and the infrared capabilities allow for night-time operations. Due to the rugged conditions and terrain in which grapple carriages are utilized, Summit provides a military grade radio system for NLOS (non-line-of-sight) communication and video.

The carriages feature a quick coupler system that ensures clean fuel and hydraulic oil and T-1 Steel construction for durability. All components are North American sourced.

Figure 3: The Summit grapple carriage

Utilising modern camera technology to improve operator vision of the grappling process has made the performance of grapple carriages much more efficient. R&M chose to install the Agcam brand of camera and include collision avoidance technology in the design to minimise the chance of unplanned contact with obstacles or the ground. Adding GPS responders to the carriage hardware would also provide the operator with up-to-the-minute location information which will be essential when automation of inhaul and outhaul becomes a reality.

HAULER REFURBISHMENT

To facilitate the removal and re-fitting of large hauler components, an eight-tonne overhead gantry crane was purchased from a local engineering firm and installed in R&M’s Whangarei workshop.

A second-hand Thunderbird TTY 70 hauler was sourced in October 2019. It was purchased from R&R Leasing Ltd in Kerikeri for $650,000 + GST. Lars Rosewarne opted to spend more than originally planned in order to get a good quality machine as opposed to buying a wreck that would require a lot more time and money to refurbish. As it turned out, even with a hauler that had a known history and appeared to be in good condition, the refurbishment required to bring it up to specification was a lot more than expected.

Once the TTY 70 was stripped down, R&M found that they had to repair cracks in the drum set and replace all the shaft bearings. Machine guarding and security panels had to be removed, modified where appropriate, and re-fitted, with most components needing to be individually painted before being re-installed. The two original hydraulic pumps were removed, reconditioned, and re-fitted to the front of the Cat 450 engine. Output from these pumps have been combined to service one circuit instead of two and together, they provide sufficient capacity to run the skyline drum motors. All other hydraulic functions such as track motor drive and stabiliser control are powered by the same circuit, (note that these functions are never required when the skyline drum motors are working).

Figure 4: The TTY70 hauler in the R&M workshop, note the overhead gantry crane.

When the sums were done, Iain May decided that to balance the power unput to the drum and reduce torque on the shaft, they would need to install two hydraulic motors on the skyline, so the drum set was modified, and new splines machined up to take the two planetary motors. Delivery of the drives from Italy was disrupted by the COVID-19 pandemic and to R&M's dismay, it was discovered that one of the variable speed motors was faulty on arrival, so a replacement had to be ordered from the supplier. Once again delivery was delayed by shipping disruptions due to COVID-19. The replacement motor finally arrived in December 2020.

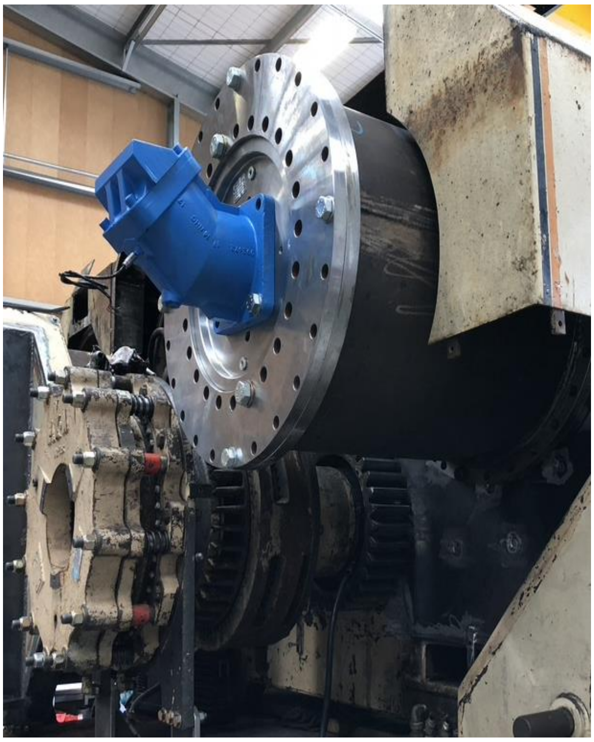

Figure 5: Planetary drive on the skyline

Figure 6: Provision for the 2nd drive.

The cab shell is one of John Deere’s latest models on their swing machines. Rosewarne & May Ltd would like to acknowledge and thank John Deere for their support in donating the cab for this project. Most of the internal components for it were built in New Zealand. The original air controls were replaced with joysticks fitted to the arm rests of the seat. They had a common layout, (similar to a processor), but the settings could be adjusted to suit personal preferences. The orientation of the cab has been angled towards the drop zone in the chute so that the operator looked straight ahead when landing the load. The idea was to minimise neck and shoulder strain for the operator, but when the realigned cab was put in place, it was too close to the drum set, creating the potential for the straw line to snag on the roof of the cab. The straw line fairlead had to be re-located to overcome this problem.

All functions can be monitored from the operator’s station on a built-in screen. Warning signals can be programmed to appear on the screen in various formats, or audible alarms triggered if the fault is deemed important enough to warrant immediate attention.

Skyline tension is continually monitored through the hydrostatic system and parameters can be set to avoid exceeding the safe working load of the rope. This means the skyline automatically winds in or out to account for the different loadings on it as drags are extracted over varying terrain conditions, (e.g., going from partial suspension to full suspension). In these situations, the operator doesn’t have to do anything, the skyline adjusts automatically.

Carriage position on the skyline and travel speeds to and from the break-out area can be displayed. At the push of a button, other data from the working cycles can be retrieved, such as the number of cycles completed during a shift or the average haul distance for a user defined period. All these parameters can be adjusted to suit operator preference.

Figure 7: Operator’s display screen.

The original air controls have been replaced by a computer fitted with a Controller Area Network (CAN bus) digital communication network, which became the Central Processing Unit, (CPU) for the hauler. It is located under the cab, which can be tilted forward to gain access to the unit. The computer is linked to sensors and microcontrollers that monitor all engine and hydraulic functions. It also has a communication network that sends and receives messages from the grapple carriage and includes a remote access function to enable off-site monitoring of performance through the CAN Bus system. Iain can dial in to the computer from any location, provided there is cellphone coverage.

It was originally intended that the hauler would have auto outhaul (to the previous break-out point), auto lowering to grapple position, auto inhaul to the landing and auto lowering to drop position at the landing. According to Lars Rosewarne, the hauler will have the capacity to automate all these functions at a later date, but R&M decided not to install them on the first prototype. The reasons for keeping inhaul and outhaul functions manual were to enable the operator to maximise payload by bunching stems at the break-out site, and to allow the operator to adjust line speeds to suit terrain conditions. It was felt that full automation was too big a step at this stage of the development.

There was no point in trying to make the tower hauler match the line speed of swing yarders because they were designed for different applications. The main difference is that a swing yarder performs best at an optimum haul distance of 300m, whereas a tower hauler operates best at up to 500m. The main constraints when logging out that distance with a tower were:

- Having to continuously adjust skyline tension to keep the drag at the right height.
- Avoiding running the carriage into obstacles or the ground.

Automating these two functions alone became key objectives of the project and were expected to reduce cycle times and improve conventional tower hauler productivity. To assist this, hydrostatic drives were fitted to the skyline drum, but manual drive has been retained in the main and tail drums.

Cracks were discovered in the fairlead of the tower and had to be repaired to achieve certification. These faults added further delays and extra cost to the refurbishment process, so for a machine that appeared to be in good condition, unexpected wear and tear has resulted in a considerable budget deficit which has primarily been born by R&M. It is recommended to future clients that these factors need to be identified and taken into consideration when choosing a hauler to refurbish.

GRAPPLE CARRIAGE DEVELOPMENT

Most components of the grapple carriage, (apart from the engine, hydraulics and cameras) were all fabricated in R&M's workshop. A 27hp Deutz motor powered the carriage functions and control is through an on-board computer which is also linked to the hauler CAN Bus system using a designated radio frequency. Live camera images are relayed to the operator who controls grapple functions using the joystick controls.

The grapple hanger bracket is connected to a centrally mounted shaft, which passes through the top of the carriage frame. Computer controlled solenoids are used to activate the grapple functions. Rotary oil union fittings, and internal hoses (tubes) mounted in the arms of the hanger bracket provide hydraulic pressure to power to the grapple functions. This internal plumbing eliminates the chances of physical damage.

One of the main benefits of having the hanger bracket suspended off a central shaft in the top of the carriage is the transmission of any sudden impact forces going directly onto the skyline rather than through the carriage. This minimises any shock loading to the motor, computer and other hydraulic components.

The hanger bracket also creates lift to the stem at the break-out phase of the extraction cycle because the grapple will swing backwards and upwards as the carriage is pulled towards the landing.

Figure 8: The rotary oil fittings on the hanger bracket shaft.

A collision avoidance system, (ground proximity sensing) is built into the carriage to prevent it from running into the ground. This ultrasonic sensor, which can be pre-set to between 1 and 25 metres above the ground, gives the operator a graphic warning on the screen when the carriage comes withing these limits. It can also be set to over-ride controls or emit an alarm for manual control. A GPS responder accurately records carriage position which can also be graphically represented on the built-in screen.

With little separation between the skyline and where the main rope attaches to the carriage, line wrap is a common problem with grapple carriages, particularly over longer haul distances. Line wrap causes significant wear to the ropes and can cause premature failure if it goes undetected.

To minimise the potential for line wrap to occur, the skyline sheaves have had 60cm long spacers installed to try and keep the two ropes apart.

The carriage was orientated with the nose down which was supposed to help minimise line wrap and reduce engine wear when extracting up-hill, (which was anticipated to be the most common extraction direction).

Figure 9: 60cm spacers connect the skyline sheaves to the carriage.

INITIAL FIELD TRIALS

The refurbished hauler and grapple carriage was delivered to Hancock Forest management's Pipiwai Forest on for field trials in December 2020. It was set up using a gravity return system over an 800m span, (although it was only yarding out to 500m). The main purpose of this trial was to get any bugs out of the system and Lars Rosewarne was keen to try it in the "worst possible situation". On the 8^{th} of December, the prototype hauler started pulling logs with a relatively inexperienced operator at the controls. It was decided to use a novice operator from the start to see how easy it would be to train someone to use the sophisticated control system in the machine.

Early results were very promising with the following feedback within a few days of operation:

- There was very little line wrap, even out over 500m.
- The skyline drum had plenty of power and the extra planetary was well worth the investment.
- The tension monitoring function was working well, constantly adjusting skyline tension.
- Monitoring skyline tension using a PID loop in the CAN bus was developing a database for future use, (when automating functions).
- The Agcam camera, working at 2.4GHz was maintaining the signal with little interference.
- The operator, Derek Rosewarne (Lars & Fiona's son), was learning fast and quickly coming up to speed.
- The hanger bracket on the carriage was working very well insulating the motor and other carriage components from shock loading.
- The spacers between the carriage and skyline sheaves were effective at keeping the carriage level during operation.

Figure 10: The refurbished Thunderbird TTY70 has worked well in early trials.

Issues that required attention were as follows:

- The carriage appeared to be losing power, it was too slow opening and closing the grapple.
- The grapple tines were too big, good for picking up a big payload but cumbersome to use, this may have been linked to the slow response from lack of power.
- The hydraulic cooling system in the hauler was an issue, operating temperatures were too high for sustained operation so a change to synthetic oil was proposed.
- The lower and raise elements on the skyline drum were too slow so the gear ratio in the planetaries needed to be changed.
- The anti-collision sensor has been removed from the development programme as it did not work as it should and it needs further development before it can be utilised.

COMMISSIONING

New planetaries were ordered for the skyline drum motors and components for the modification of the carriage and grapple were sourced with the work scheduled for early 2021. Once again supply issues delayed the proposed changes so in January 2021, the prototype hauler went into full production, replacing the original hauler in Rosewarne Cable Loggers Crew 60 in Pipiwai forest. At this point, the new planetaries hadn’t arrived and the modifications to the carriage had not been done. The crew configuration consisted of five employees and their duties were as follows:

1. One person, predominantly manual falling, but employing mechanical felling where terrain permitted.
2. One person operating the hauler using grapple extraction to the landing,
3. One operator partially processing stems into off highway trucking lengths using a Komatsu machine with a Waratah processing head.
4. A off highway truck driver transporting the semi-processed stems to the processing landing.
5. One operator processing the partially processed stems into logs and loading highway trucks with a loader.

Daily production before the automated hauler and grapple carriage turned up averaged about 200 tonnes per day. Within days of shifting into the crew the new hauler was meeting their production target. Since then, in the period from February to April 2021, it has reportedly averaged 280 tonnes per day, consistently exceeding the expectations of Rosewarne Cable Loggers Ltd., given it is a prototype machine.

Figure 11: The grapple carriage had a few issues and required modification.

The grapple carriage ~~on the other hand~~, has had a few issues and required some modification to bring it up to production standards. After the initial field trial, it was found that the grapple tines were too big and cumbersome to control and the opening and closing functions were too slow. It was also felt that the motor in the carriage was under powered. Lars and Iain decided to cut the tines down to make them nimbler and reduce the weight, but in the process the shape of the tines changed, and when the carriage went back into service, stems were regularly slipping out of the grapple. On one occasion, a stem slipped out of the tines as the carriage was approaching the landing and the sudden release of tension caused it to ricochet forward, crashing into the hauler tower. Fortunately, damage was minor, but the incident did raise safety concerns and further modification was planned to address the problem.

Another unexpected problem arose in foggy conditions when the operator had the ACME mechanical slack pulling carriage on. Unfortunately, the main rope crossed over the skyline and was unsighted by the operator, the resulting friction cut through the skyline causing it to fail. To mitigate this happening with the grapple carriage on, R&M decided that when it was modified, they would install two extra cameras, one facing back towards the hauler and the other facing out towards the tail hold.

Some of the guarding on the carriage was a bit light and contact with up-ending stems and various other obstacles, (not to mention the contact with the tower when the stem slipped out) meant that extensive modification of the carriage would be required before any performance trials were conducted. This would be a planned occurrence and scheduled to coincide with a change in settings where the grapple carriage would be unsuitable for the logging conditions.

A field demonstration was held on the 7th of April 2021 when stakeholders in the project were invited to visit the workshop where the hauler was refurbished and the grapple carriage was built, followed by a trip out to Pipiwai forest to the hauler and carriage working (Appendix 1). Over 30 people turned up to the day which was successfully hosted by R&M, Hancock Forest Management and Forest Growers Research.

The grapple carriage was taken out of service in July 2021 so that solutions to the above problems could be found. The following modifications were proposed:

- The slow opening and closing speeds were believed to be a function of engine horsepower so a larger motor was ordered.
- To improve weight distribution, the engine was re-orientated 180^{o} in the carriage chassis and the battery was relocated to protect it from the effects of sudden impact.
- The anti-collision sensor also had to be relocated to a position lower in the carriage chassis.
- The shape of the grapple tines was changed to increase the contact area with the stem.

- A brake was fitted to the central shaft that the hanger bracket is suspended from.
- Extra cameras have been installed to improve operator vision of the wider breakout area.

Unfortunately, not all these modifications were completed before the carriage went back into service.

PRODUCTION STUDY RESULTS

In March 2022 a two-day production study was undertaken of the semi-automated hauler and grapple carriage working in Manulife Forest Management's Hikurangi Forest, (Harvest Area 4391). The operation was extracting 28-year-old Radiata pine with an average piece size of 1.85m^3 according to the stand data. The setting had a 60 metre deep gully running through the middle of it and a Class 5L stream in the bottom of the gully.

The hauler was rigged with the tower at 50' and a Komatsu D65 mobile tail hold was stationed on the backline to facilitate line-shifts. A John Deere 909 with a Southstar felling head was used to fell the trees and the stems were being semi-processed from the chute by a Komatsu PC300 with a Waratah 626 HTH processor. The partially processed stems were being loaded by a John Deere 2156G grapple loader onto a Bell TH403EN off-highway vehicle and transported down Pylon Road to a processing yard on Gerrard Road. The operation was run by a crew of 9 workers.

Continuous time study data was collected for 194 cycles over the two-day period. Note that the first three hours of the first day were missed due to delays in arrival through disruption of travel plans). Landmarks were used to determine average haul distances, and these were checked after hours using a laser range finder). The data from the processor in the chute was used to determine average volume per cycle. Drags were visually assessed for the number of stems and pieces in them and recorded as follows:

- Butts obviously over 10m long were counted as a stem.
- Anything merchantable under 10m long was recorded as a piece.

The volume processed by the processor was then reconciled with the number of stems and pieces in each drag to establish a volume per cycle. Figure 12 shows the setting from the backline.

Figure 12: Photo of the setting in HA4391 taken from the backline.

Results from the Production Study.

The results from the production study are summarised in Table 2.

Table 2: Summary of production study results.

Element:	Average per Cycle:	Range: (Max & Min)	Number of Observations:
Outhaul – (Seconds)	*45.2*	*14 – 109*	*193*
Lower – (Seconds)	*14.2*	*0 – 72*	*188*
Grapple – (Seconds)	*43.3*	*7 – 218*	*193*
Inhaul – (Seconds)	*69.4*	*23 – 141*	*193*
Delay Free Time – (S)	*173.0*	*58 – 355*	*194*
Delays – (Seconds)	*80.0*	*0 – 1516*	*71*
Total Cycle Time – (S)	*253*	*78 – 1659*	*194*
Haul Distance – (M)	*205.9*	*20 – 295*	*193*
Number of Stems	*0.89*	*0 – 3*	*176*
Number of Pieces	*0.45*	*0 - 3*	*87*
Volume per Cycle (m^3)	*2.3*		*172*

The elements in the extraction cycle were as follows:

- Outhaul begins when the drag is dropped in the chute and the operator engages the tail rope.
- Lower starts when the tail rope stops and ends when the grapple is positioned above the drag.
- Grapple starts as the grapple is lowered onto the drag and ends when the drag is picked up.
- Inhaul starts when the drag starts to move and ends when it is dropped in the chute.
- Delays were anything that disrupted the normal pattern of the extraction cycle.

From Table 2, Delay Free Cycle times averaged 2.88 min, which equates to 68% of the total cycle time (Figure 13). The average total cycle time (4.22 minutes) does not include smoko or personal delays.

Obviously, the outhaul and inhaul times were representative of the distance travelled, but there was considerable variation in these times, particularly during outhaul. This could have been a function of the operator's limited visibility of the terrain because travel speeds appeared to be slower than what would normally be expected. The "lower" grapple element in the cycle was also dependent on where the carriage was located in the profile.

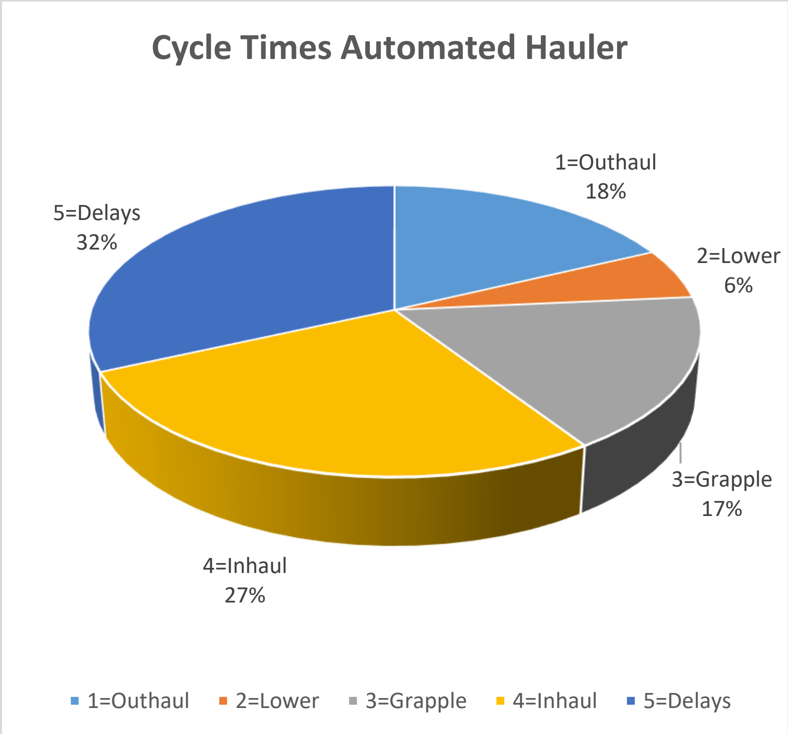

Figure 13: Proportion of total hauler cycle time.

Inhaul times were also affected by the type of drag that had been grappled. Closer analysis of delay free times showed that the average cycle time for butt pulls was two minutes, 59 seconds. Average head pull times were three minutes 11 seconds, (7% longer). The average cycle time for gut hooks was three minutes 28 seconds, (16% longer). The average time when just pieces were extracted was two minutes, 19 seconds. Based on the extra $13^1/_2$ minutes taken to extract and land the head-pulled and gut-pulled drags, the equivalent of five cycles were lost during the observations, which equated to approximately 11.5 m^3.

But the slower cycle time referred to above does not take into account the breakage and re-grappling elements recorded as delays in the full cycle times. On average, one minute and 20 seconds were lost in delays each drag. Table 3 shows a breakdown of the delay elements recorded during the study.

Table 3: Details of delays per cycle, excluding smoko

Delay Element:	**Average per Cycle:**	**Range: (Max & Min)**	**Number of Observations:**
Breakage – (Seconds)	*3.79*	*0 – 180*	*7*
Non-Merch – (Seconds)	*4.64*	*0 – 184*	*10*
Re-Grapple – (Seconds)	*8.13*	*0 – 825*	*8*
Line Wrap – (Seconds)	*2.70*	*0 – 273*	*4*
Stalled – (Seconds)	*0.83*	*0 – 66*	*3*
Landing – (Seconds)	*3.11*	*0 – 128*	*14*
Line shifts – (Seconds)	*45.82*	*0 – 1516*	*16*
Other – (Seconds)	*10.97*	*0 – 625*	*9*
Total Delays – (Seconds)	*80.01*	*0 – 1516*	*71*

Some of the delays were essential, e.g., line shifts, but others, such as breakage and picking up non-merchantable material appeared to be avoidable, so minimising them would reduce total cycle times and improve the productivity of the operation. Figure 14 gives a graphic illustration of the delay times.

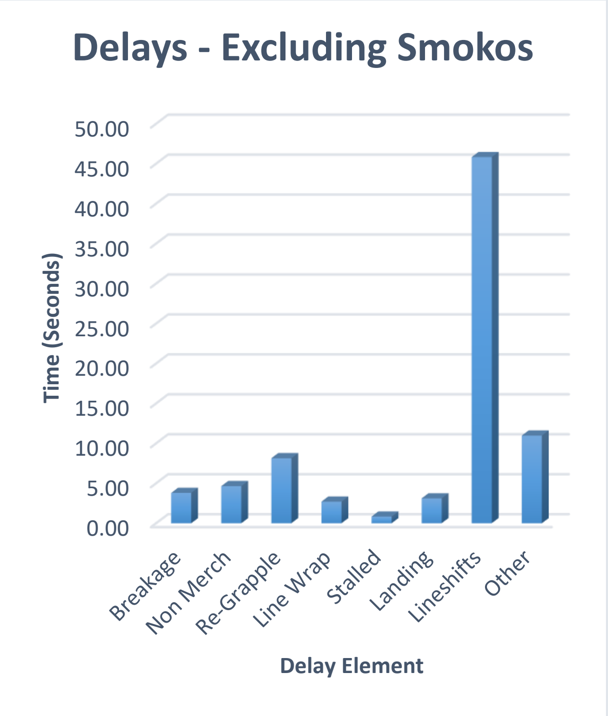

Figure 14: Delays per cycle.

On one occasion, thirteen minutes was lost attempting to pick up a stem that had slid out of reach of the grapple. The tail rope was off-set from the skyline and this was creating a swing in the ropes which placed the carriage close to the target, but the hauler operator could not drop the ropes quickly enough to land the grapple on the stem. In the end, the spotter had to reposition the tail hold back over dead ground to enable the stem to be picked up.
Line shifts accounted for 57% of the delays and just over 18% of the total cycle time. This is not uncommon in grapple hauler operations, especially tower haulers because there is limited lateral yarding capacity. It was felt that bunching stems with a fixed head felling machine would reduce breakage, improve payloads, and reduce cycle times.

While felling costs are likely to increase with a fixed felling head, other research shows that overall productivity of the operation would improve.

At almost 11 seconds per cycle, "Other" delays accounted for a significant proportion of delay time. While some of these delays were routine, e.g., maintaining the carriage and checking the pole alignment after a line shift, others like waiting for tree felling, scanning the line for missed stems and processor maintenance were hold ups that could have been reduced or even avoided. Examples of this are tree felling and maintaining the processor during productive time. Perhaps elements like scanning the line for missed stems could be reduced.

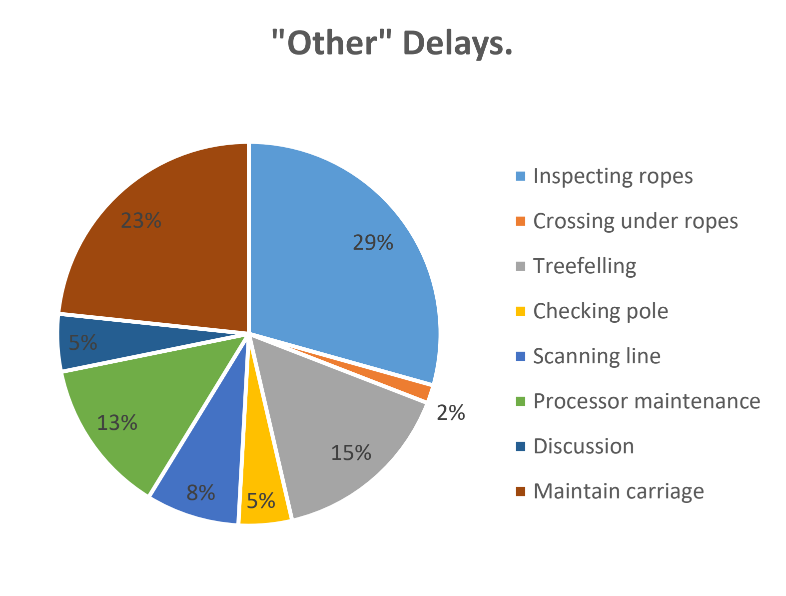

Figure 15: Breakdown of "Other" delays.

Further production studies are planned of a mechanically driven 70' tower, preferably a Thunderbird, with a similar type of motorised grapple carriage later in 2022. It is proposed that the same format as used in this study, will be followed when data is collected on the mechanically driven hauler. Care will be taken to ensure terrain and stand conditions are similar so comparisons can be made to measure the effects of automating the skyline tensions and using the grapple carriage.

FUTURE DEVELOPMENT PLANS

Future plans for the project are to operate the prototype hauler and grapple carriage in a full production situation in RCL's Crew 60 for the next three to four months to enable the new operator, Cam McRae, to become fully conversant with the hauler and carriage. Production will be monitored over this period and any further modifications needed will be made as they arise.

Once R&M are happy that the hauler and carriage are performing to specification, a full production study will be undertaken by FGR to measure the effects of the current level of automation. It is proposed that more data will be collected on; cycle times, payloads extracted, delays encountered, and manpower required to safely operate the automated hauler

Drone technology will be used to collect cycle times, and this will be analysed to break the extraction cycles into element times. Payload volumes will be based around daily production through the processing machine, breaking the stems down into suitable lengths for the off-highway transport system. It is expected that the data collection will be completed by June 2022 and at that stage, a second field demonstration will be scheduled to present the project to the wider forest industry.

The CAN bus control system will be programmed to collect long term data during the phase one study and this information will be used to guide phase two developments, such as further automation of the extraction cycles.

Phase two of the project will include increasing the amount of automation of extraction elements, including:

- Automated outhaul and lower to the load grapple position.
- Operator training programs to maximise efficiency.
- Refinement of the anti-collision mechanism.

- Adjustment of camera footage to better inform operator decisions.

It is anticipated that these developments will be undertaken in the second half of 2022, (Covid permitting). Once they have been implemented and tested, the effects of these modifications will again be measured using the same production study technique.

Depending on progress, a parallel study using camera technology to identify the optimum drag make up will be trialed as a further step towards full automation of cable extraction procedures. A Request for Proposals was issued for this stem recognition technology in December 2020 and negotiations are underway with Lincoln Agritech who have undertaken to develop the concept. It is proposed that the Stem Recognition technology will be included in phase two of this project.

FGR expects the Automated Hauler and grapple Carriage project to be completed by the end of the 2022/23 financial year, when an industry-wide field demonstration of all the outcomes from the project is likely to be undertaken.

ACKNOWLEDGEMENTS

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- Lars and Fiona Rosewarne, Rosewarne Cable Loggers Ltd, Whangarei.
- Iain May, Rosewarne & May Limited, Whangarei.
- Andrew Widdowson, Manulife Forest Management (NZ) Ltd., Whangarei.
- Will Steward, Rayonier Matariki Forests, Whangarei.
- Forest Growers Levy Trust.
- Ministry for Primary Industries.

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APPENDIX 1: FIELD DEMONSTRATION FLYER

FOREST GROWERS RESEARCH

Field Demonstration of the Rosewarne Integrated Carriage and Hauler, Pipiwai Forest, Whangarei

Wednesday 7th April, 2021

Dear Industry Member

You are invited to attend the field demonstration of the Rosewarne Integrated Carriage and Hauler in Pipiwai Forest, 50km north-west of Whangarei, on Wednesday 7th April 2021.

This field demonstration of this semi-automated Thunderbird TTY70 hauler and grapple carriage is part of Forest Growers Research PGP programme in forestry automation. The field demonstration is hosted by Hancock Forest Management (NZ) Limited, Rosewarne & May Ltd and Rosewarne Cable Loggers Ltd.

The semi-automated hauler and grapple carriage was designed and built by Rosewarne & May Ltd, Whangarei specifically to improve grapple extraction and reduce workload of the hauler operator. The project has been co-funded by Rosewarne & May Ltd, Hancock Forest Management (NZ) Limited, Rayonier Matariki Forests, the Ministry for Primary Industries, and the Forest Growers Levy Trust.

We will visit Pipiwai Forest, owned by Taumata Plantations Ltd and managed by Hancock Forest Management (NZ) Limited, to view the Rosewarne Integrated Carriage and Hauler in operation in a radiata pine clearfell harvesting operation. The hauler will extract full tree stems from a steep gully to the landing, where visitors will have the opportunity to view the semi-automated hauler and grapple carriage close up. The site has good access and safe viewing of the operation for all demo participants.

When: Wednesday 7th April 2021

Time: 9:00am – 4:00pm

Where: Bus transport from Rosewarne Cable Loggers,
55 South End Avenue, Raumanga, Whangarei 0110

Cost: Field trip is funded by Forest Growers Levy Trust (includes lunch and drinks and field handout).

Gear: Please bring your own safety helmet, hi-viz vest and sturdy footwear.

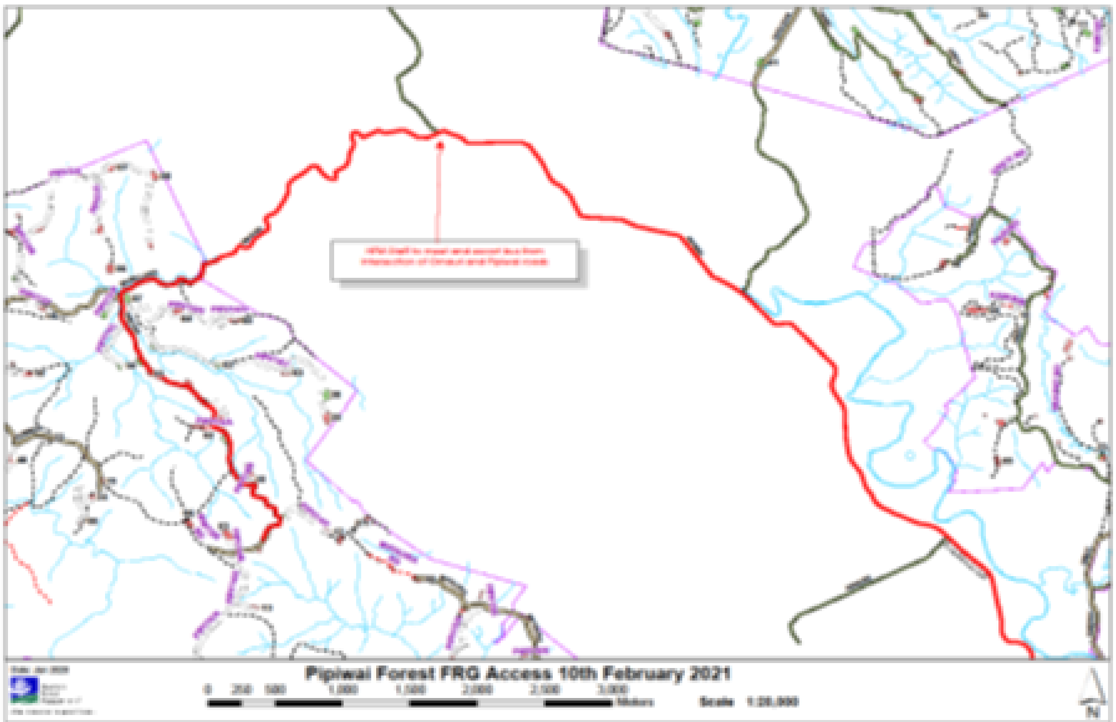
Who should attend: FGR Harvesting Technical Steering Team and researchers, and the PGP Programme Governance Group.

Numbers are limited to 24 people. If you wish to attend, please RSVP to Veronica Bennett at FGR: veronica.bennett@fgr.nz or phone 07 921 7246. Please use the bus transport provided. No separate utility vehicles will be allowed into the forest.

RSVP: Thursday, 1st April 2021

ITINERARY

Time	Activity	Details
9:00am	Meet at Rosewarne Cable Loggers, Whangarei	55 South End Avenue, Raumanga, Whangarei
9:15am	Bus departs Rosewarne Cable Loggers, Whangarei	
10:15am	Bus arrives Pipiwai Forest; Introduction to Taumata Plantations Ltd and Pipiwai Forest and Safety briefing	Andrew Widdowson, Regional Manager HFM NZ Ltd
10:45am	Bus arrives at Rosewarne Cable Loggers 60 site, Background to development of automated hauler	Lars Rosewarne and Iain May
11.00am	Demonstration of the Rosewarne Integrated Carriage and Hauler (ICAH) in action	All visitors
12:00pm	Lunch	Lunch provided by FGR
12:45pm	Close up viewing of the grapple carriage and hauler on the landing	All visitors
2:00pm	Question and Answer session / general discussion	Keith Raymond, FGR
2:30pm	Bus departs Pipiwai Forest for Whangarei city	Winter Rd / Omauri Rd
4:00pm	Bus arrives Rosewarne Cable Loggers, Whangarei	55 South End Avenue, Raumanga, Whangarei



supported by forestgrowers commodity levy