HARVESTING TECHNICAL NOTE

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Innovative Yarding System – Technical and Economic Feasibility

Summary

The Innovative Yarding System project aims to develop a new yarding system to increase harvesting productivity and reduce the cost of cable yarding. Developing new prototype products may also provide an opportunity to grow the harvesting machinery manufacturing industry in New Zealand. Earlier work has reported the concept generation and analysis of ideas through an expert panel to improve the way cable harvesting is undertaken in New Zealand. Arising from this earlier work a new idea was taken forward for further development. The chosen concept is a system comprising a low cost yarder and three innovative logging carriages controlled remotely. This report details the initial concept, the technical feasibility appraisal conducted, and initial economic analysis. A comparative analysis of expected cost and productivity of the Awdon concept compared with more typical current cable harvesting systems showed there was good potential to reduce harvesting costs.

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BACKGROUND

Previous comparisons of different yarding approaches have identified the advantages of grapple yarding, such as very short load accumulation times relative to the time to manually attach chokers. Part of the FFR Steep Land Harvesting Programme has involved development of improved grapple yarding systems to replace the use of manual chokers, eliminating the roles of the breaker out and pole man, and reducing the time to "hook on" and unhook logs using chokers. Preliminary simulation undertaken for the original PGP Harvesting Business Plan indicated the combination of felling, bunching and grapple yarding had the potential to deliver net cycle time benefits of about 30% [1].

Radio-controlled yarder carriages, as used in European yarders (for example, Syncrofalke, Koller and Valentini yarders), incorporate automation of "outhaul" and "inhaul" using computer control to deliver the carriage to the point of the previous load. Elements of this system are proposed in the FFR programme to direct the grapple/carriage to the next load.

A recent survey of cable haulers in New Zealand [2] found only 38 out of 305 haulers (12%) were manufactured in New Zealand (Brightwater or Harvestline haulers). Developing new prototype products may provide an opportunity to grow the harvesting machinery manufacturing industry in New Zealand.

Earlier work generated and analysed concepts for an innovative yarding system [3, 4]. A new concept was proposed by Awdon Technologies Ltd (Awdon), a design and development company from Gisborne, New Zealand. An international search of literature on the features of this system, such as grapple yarding, remote control, self-propelled carriages and automation did not reveal any existing patents or publications that were similar to the Awdon concept [5].

The criteria for an "innovative" yarding system were agreed by an expert panel established to guide the project. These were: the concept had to be a yarding system (not any other type of harvesting system); it had to be achievable in terms of cost and timeframe; and it had to be new to New Zealand. The Awdon concept met the criteria for an innovative yarding system.

In late 2013 an alpha prototype development plan was developed that specified the operational parameters and performance standards for the system. This report summarises the concept and reports the broad level technical and economic feasibility analysis undertaken.

CONCEPT DESIGN

The concept involved a low cost two-drum yarder with a remote control system driving three innovative logging carriages: a mobile tail-hold carriage, a self-propelled grapple carriage, and a lateral yarding carriage.

The mobile tail-hold carriage anchors the skyline of the cable yarder and contains two winch lines that are separately anchored 60 m to 70 m apart at the back line of the cable setting. Letting one of the winch lines slacken while winding in the other would allow the tail-hold carriage and skyline to be moved sideways.

Working in unison with the tail-hold carriage, the self-propelled hydraulically operated grapple carriage would be able to pick up trees anywhere in a triangular segment of the setting rather than from just the area directly below the fixed skyline. The proposed carriage drive mechanism is two hydraulically powered high pressure tyres. The tyres, which will be forced onto the skyline, will drive the carriage out at high speed (10 m/s) and the mainline will pull the carriage in. The tyres will also act as a dynamic brake for slowing the inhaul when logging the back face of a setting.

The third carriage with lateral yarding capability has been designed with its own winch, which will deflect the skyline sideways in a “Dutchman block” setup. The advantage of this is that low deflection areas of the setting, often logged using a “scab” or running skyline system, can be logged with the grapple carriage.

The proposed yarder was a low cost track-based tower with a two-drum hydraulic winch set (Figure 1). It was proposed that having a fast carriage return, automated skyline shifts and integrated controls had the potential to deliver net cycle time benefits of approximately 25%. More constant power and continuous loading from hydraulically powered systems will also reduce wear and tear on engines and reduce fuel consumption. This system enables good payloads to be achieved when mechanical felling and bunching is not possible.

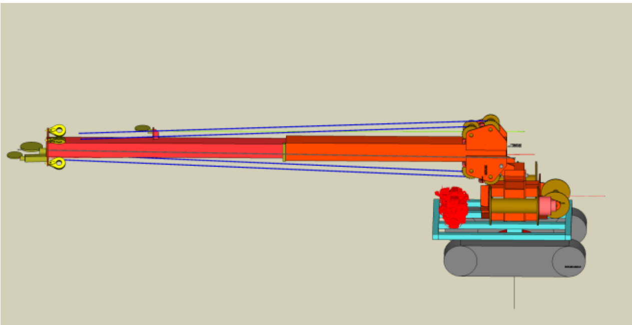

Figure 1: Innovative hydraulic yarder design

The innovative features of this system include:

1. The tail hold carriage will reduce the skyline shift time.
2. The self-propelled grapple carriage will operate on a two-drum yarder (not requiring a tail rope).
3. The lateral yarding (Dutchman) carriage can reach areas of low deflection.
4. All carriages are synchronised via a single lever control system.

Operating Parameters and Performance Specifications

The operating parameters and performance specifications of the innovative yarding system, as determined by the expert panel, are listed below.

The grapple carriage (Figure 2) shall meet the following specifications:

1. Out haul speed of 10 m/s
2. Weigh <1.4 tonnes
3. Ability to grab two trees
4. Grapple opening of >1.7 m
5. 360^{0} grapple rotation
6. Powered by diesel engine
7. Grapple powered by hydraulics
8. Self-propelled variable drive system
9. Carriage to be remote controlled from the hauler
10. Carriage to have on-board cameras and lights
11. Low cost.

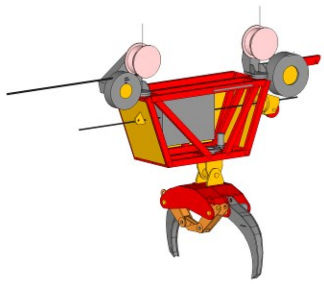

Figure 2: Concept drawing of grapple carriage with tyre-drive mechanism

The mobile tail hold carriage (Figure 3) shall meet the following specifications:

1. One or two small winch drums capable of carrying 100 m of 26-mm to 28-mm rope
2. The winch drums to have pulling power of at least 4 tonnes
3. Have walk over guy capability
4. Carriage to weigh <1.2 tonnes
5. The winch drums to have rope spooling capability
6. The carriage to be remote controlled from the yarder
7. On-board camera system to watch winch drums

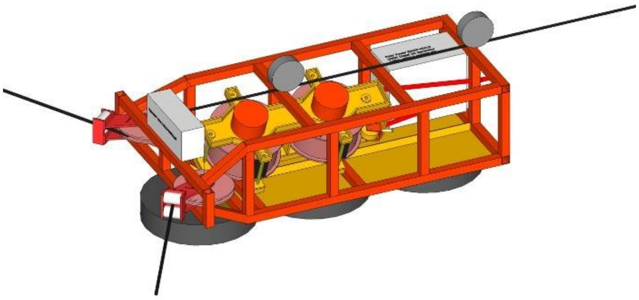

Figure 3: Mobile Tail Hold carriage with twin capstan winches

The lateral yarding carriage (Figure 4) shall meet the following specifications:

1. 150 m of cable of a size suitable to handle loadings
2. Weigh <1000 kg
3. Be self-clamping
4. Be remote controlled from the yarder
5. Have an option to allow the grapple carriage to pass
6. The winch to have enough power to achieve lateral yarding.

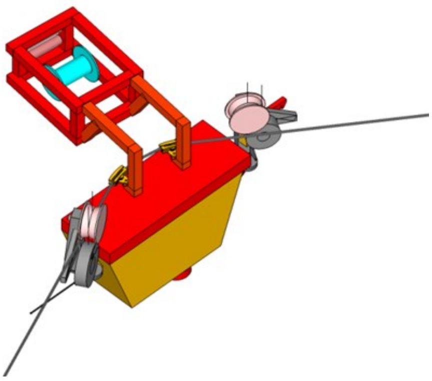

Figure 4: The lateral yarding carriage concept showing the grapple carriage traversing past it

A provisional patent for the innovative yarding system including the individual components making up the system (carriages and yarder) has been filed by Awdon.

TECHNICAL FEASIBILITY

Grapple Carriage

One requirement of the design was that the tyre drive mechanism for the grapple carriage would have to achieve fast carriage outhaul speed and dynamic braking. While a number of conceptual drive mechanisms were developed, the tyre drive system remains the focus of the Awdon technology. Early evaluation of the drive wheels indicated outhaul speed of approximately 10 m/s was achievable. It was estimated that the grapple carriage would weigh two tonnes (heavier than desired specification). Payload analysis showed that even though the expected weight was heavier than desired, the system would still work if the appropriate deflection in the skyline was achieved.

An extensive literature search showed that the tyre drive mechanism of the grapple carriage as proposed by Awdon is unique [(5)].

A static test jig was built to test the ability of rubber tyres to drive the carriage. It was quickly established the tyre must be capable of withstanding high pressure to allow the tyre to be forced onto the skyline to provide adequate traction. A search for such a tyre led to the purchase of a front tyre of a F14 jet fighter which is capable of working at 300 psi (Figure 5). The test jig trials showed the F14 tyre would generate the drive requirements.

Figure 5: Front tyre of F14 fighter jet to be used to drive the grapple carriage

Given that one of the design goals of the grapple carriage was to operate successfully without a tail rope it was agreed the drive mechanism would require dynamic braking capability to slow the carriage when extracting from the back face of a setting. A new test jig was designed and built to carry out the dynamic braking testing (Figure 6).

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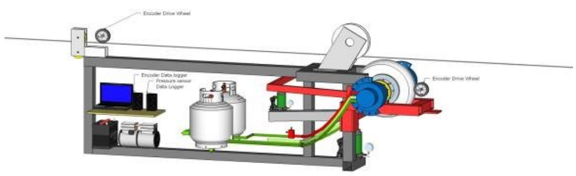

Figure 6: Sketch-up design of dynamic test jig

The testing of the dynamic braking at full scale enabled absolute certainty that the drive mechanism would meet all the requirements prior to building an alpha prototype. The test jig design incorporated encoders to measure slippage of the tyre on the skyline at differing tyre pressures and at different settings on the hydraulic brake motors. Construction of the test jig is shown in Figure 7. The gas bottles were filled with hydraulic fluid under compression to provide the dynamic braking and avoid cavitation during the test.

Figure 7: Dynamometer test jig being built

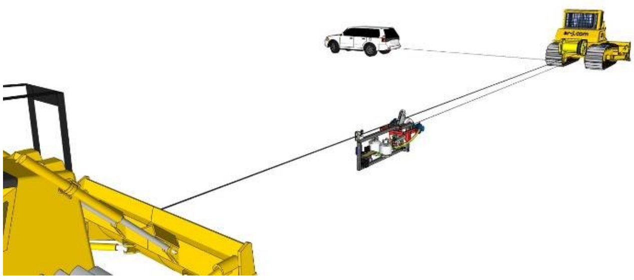

Figure 8: Dynamic test jig setup.

The layout of the dynamic test jig during testing is shown in Figure 8. The skyline is strung between two machines with the mainline pulled by another vehicle.

Tail Hold Carriage

The first tail hold carriage design incorporated two winch drums and was estimated to weigh two tonnes, much more than the development plan target of 1.2 tonnes. To further complicate the design, an independent engineer reviewed the design and stated that the twin winch system needed to be interlocked to have any level of efficiency in terms of power requirements. The independent engineer undertook calculations to determine the line pull and speed for interlocked and non-interlocked winch systems. The calculations showed that a 100-kW engine would have been required to provide the power requirements for a non-interlocked winch system to meet design specifications.

In order to investigate smaller power requirements and therefore lower the weight, the engineer also produced further analysis showing that a 30-kW engine would be required for an interlocked winch system. Interlocking the twin-winch concept however increased the weight of the carriage. Consequently other options were explored. One option explored was to use a single capstan winch, but a 1/8th scale model (using 4-mm wire rope) did not work due to spooling inadequacy. Another option was to have a twin capstan winch arrangement common in other high load requirement industries. Awdon developed a design for a twin capstan winch. A 1/20th scale twin capstan tail hold model was built (Figure 9) and it worked well.

Figure 9: A 1/20th scale model of twin capstan system

The estimated weight of the twin capstan tail hold carriage was greater than the desired specification. A further option explored was use of synthetic rope to reduce weight, and this has helped to simplify the carriage designs.

Lateral Yarding Carriage

The concept of the lateral yarding carriage design is to use a single integrated winch to deflect the skyline sideways and meet the performance specifications outlined above. As the mobile tail hold carriage incorporates some of this function, development of the lateral yarding carriage was ranked lower priority, and further work will be delayed until after the mobile tail hold carriage prototype is completed.

Yarder Design

Two concepts for the yarder design were developed, one with integrated boom, arm and grapple (Figure 10). These designs will not be taken further until the prototypes of the mobile tail hold carriage and self-propelled grapple carriage have been completed.

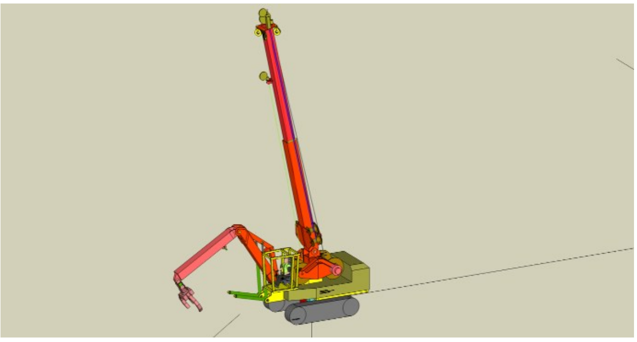

Figure 10: Innovative yarder design (#2)

ECONOMIC ANALYSIS

Payload Analysis

Analysis of tension, deflection and payload was undertaken by Dr Rien Visser of the University of Canterbury School of Forestry to determine the effect of the tail hold carriage weight on potential skyline payload.

A spreadsheet analysis was used to calculate the tension in the skyline at a stated deflection (Table 1). For the analysis it was assumed the tail hold carriage and the grapple carriage weighed 2.0 tonnes (4,400 lbs). At 7.5% deflection, the skyline tension was calculated to be 46,359 lbs. This tension figure was then used to calculate the proportion of the deflection in the skyline that is used by the weight of the tail hold carriage.

The analysis showed that 0.4% of the skyline deflection (originally 7.5%) was used holding the tail-hold carriage off the ground when sited near the backline. This loss in deflection reduced the total available deflection in the skyline to 7.1%.

Table 1: Tension, Deflection and Payload analysis (imperial units of measure)

Skyline Calculations Rien Visser, Virginia Tech	Calculate for*: Tension	 Deflection	 Payload
Skyline Tension (lbs)		46359	46359
Percent deflection (%)	7.5		7.1
Payload (lbs)	8000	0	
Carriage weight (lbs)	4400	4400	4400
Cable weight per foot (lbs/ft)	1.65	1.65	1.65
Cord length (ft)	1500	1500	1500
Carriage position (ft)*	750	1450	750
Cord slope (%)	20	20	20
	46359 (lbs) Tension	0.4 (%) Deflection	7274 (lbs) Payload
			3306 (kgs) Payload

$$Deflection\,(\%) = \frac{y_m}{l_d}\cdot 100$$

$$Tension = \frac{(C+P+\frac{1}{2}q\cdot l_d)\cdot(x(l_d-x))}{\%\cdot l_d^2\cdot\cos\theta}$$

With a 2.0 tonne tail-hold carriage and a 2.0 tonne grapple carriage on the skyline at 7.1% skyline deflection, the maximum payload that could be achieved while remaining within the safe working load of the 28-mm skyline was calculated to be 7,274 lbs or 3.3 tonnes.

Costing

A desk-top feasibility analysis was undertaken. This compared the Awdon concept with current cable harvesting systems to investigate the likelihood of the new system meeting the overall project goal of reducing cost by 30%.

For the comparison, all operations were two-stage capable and included mechanical processing. For the purpose of the cost analysis, assumptions regarding capital costs were: swing yarder $1.8 million; conventional tower $1.6 million; and Awdon yarder $1.1 million.

The Awdon yarder, being hydraulic, was assumed to have a slower inhaul time. Due to the hydraulic grapple carriage having a bunching arm (capable of handling more than one tree per cycle on occasion) the grapple time was assumed to take longer than a

standard grapple with the benefit recognised in a higher average number of trees pulled per cycle.

For the analysis of the current grapple yarder, the impact of extracting small pieces (tops) was accounted for by setting the number of trees per cycle at less than one. Table 2 shows the Awdon idea being capable of improving costs by up to 23%.

The productivity and cost analysis in Table 2 assumed a more conservative payload of 2.4 tonnes per cycle to estimate the potential harvesting cost of the proposed Awdon system in comparison to conventional systems.

Table 2: Cost comparison of current harvesting systems to Awdon Triple Carriage System

Elements	Current Grapple Swing Yarder Operation including 2-stage and Processor	Current Swing Yarder MSP Operation including 2-stage and Processor	Current Standard Tower Operatio including 2-stage and Processor	Awdon Technologies Triple Carriage System including 2-stage and Processor
Piece size (tonne)	**2**	**2**	**2**	**2**
Minutes per day available to work	**480**	**480**	**480**	**480**
Haul distance (m)	**280**	**280**	**280**	**280**
Out Haul (sec's)	30	30	30	46
Position Grapple (sec's)	10			10
Position butt rigging (sec's)		20	20	
Grapple (sec's)	30	0		45
Hook-on (sec's)		240	240	
In Haul (sec's)	45	60	60	120
Drop Load (sec's)	5	10	10	10
Un-hook (sec's)		30	30	
Lift Ropes (sec's)	5	5	20	5
Cycle Time (minutes)	**2.08**	**6.58**	**6.83**	**3.93**
Contingincy 10% (minutes)	**0.21**	**0.66**	**0.68**	**0.39**
Time Per Cycle (minutes)	**2.29**	**7.24**	**7.52**	**4.33**
Move backline minutes per day	15	15	23	8
Reposition Hauler minutes per day	23	8	8	4
Rig up minutes per day	8	8	11	8
Rig down minutes per day	8	8	11	8
Mechanical Delay minutes per day	8	8	8	4
Operational Delay minutes per day	15	15	15	8
Cycles per day	**177**	**58**	**54**	**102**
Tonnes per cycle	**1.60**	**4.40**	**4.40**	**2.40**
Trees per cycle	0.8	2.2	2.2	1.2
Production per Day (tonnes)	**283**	**255**	**237**	**245**
Day Cost of Operation ($)	**9,719**	**9,702**	**9,794**	**7,788**
Unit Rate ($)	**34.37**	**38.02**	**41.31**	**31.73**
% Improvement	**8%**	**17%**	**23%**	

CONCLUSION

A process of idea generation and analysis was undertaken to confirm the concept design of the Innovative Yarding System.

The concept designs for the carriages and yarder, that meet the operating parameters and performance specifications of the Development Plan, have been completed.

Engineering drawings of the alpha prototype carriages have been completed. Awdon have completed three-dimensional concept drawings of the grapple carriage and tail hold carriage. Two concept drawings for the lateral yarding carriage and two concept drawings of the yarder have also been completed.

For the grapple carriage, Awdon has put a huge amount of effort into proving the tyre drive mechanism prior to building an Alpha prototype, to be sure that the rubber tyres will be capable of driving and dynamic braking. Full scale test jigs have been developed to test both drive capability and dynamic braking capability. The tyre drive of the grapple carriage was tested on a static jig which showed that a rubber tyre would be capable of having enough friction to drive the carriage out.

A test jig was built where hydraulic motors acting as brakes could simulate what might happen in a real life logging scenario. What was less certain was the capability of the rubber tyres to act as a dynamic brake to slow down the carriage and the trees when harvesting the back face of a setting.

For the tail hold carriage, an independent engineer showed the winch drums on the twin winch tail-hold carriage needed to be interlocked to achieve the desired speed and line pull. Given the agreed specified weight restriction, other concepts were investigated for the tail hold carriage. The investigation of use of synthetic rope simplified the twin winch design and allowed that particular design to be considerably lighter and therefore the more favoured option.

Initial technical and economic analysis has shown that the system is feasible from a technical point of view. The design process undertaken by Awdon prior to building an alpha prototype has been rigorous to ensure the design, particularly of the drive mechanism of the self-propelled grapple carriage, will work.

A comparative analysis of expected cost and productivity of the Awdon concept compared with typical current cable harvesting systems showed there was good potential to reduce harvesting costs.

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