HARVESTING TECHNICAL NOTE

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Productivity of the Koller K602H Yarder in Radiata Pine

SUMMARY

This report is the second part of a project to assess the performance of the Koller K602H, a modern European cable yarder which was introduced into New Zealand in January 2015. The yarder had previously been studied in small piece size Corsican Pine at Mangatu Forest, near Gisborne, and this study was a follow up to assess the yarder's performance in radiata pine. The Koller yarder differs significantly from the North American cable yarders commonly used in New Zealand. It is remotely operated, has semi-autonomous functionality, a relatively low capital cost, and is significantly more fuel efficient than the North American yarders. The study was conducted at a forest in the East Cape region of the North Island, and included productivity measures through time study, skyline tension monitoring, assessment of noise levels and breaker-out work levels. Results showed hourly productivity of 32.0 m^3 per productive machine hour, which indicated that the yarder had comparable hourly productivity to current New Zealand yarding equipment. During the study however, machine utilisation was only 47% resulting in production per scheduled machine hour (SMH) of only 15.0 m^3/SMH.

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INTRODUCTION

In New Zealand cable logging costs have steadily increased over the last six years of benchmarking data collection[1] due to increasing labour and machinery costs. Log prices have remained relatively static over the same period, resulting in reduced returns for owners of steep country forests. If the cost of harvest continues to increase at the same rate and log prices remain static, many forests may become uneconomic to harvest in the near future, particularly small, steep terrain forests remote from mills or ports.

It is important for the growth of the forest industry to be able to harvest these areas economically. Smaller scale forest owners (those owning less than 1000 hectares) made up 30% of the national plantation forest estate in 2015[2]. Forecasts indicate that the availability of radiata pine from the New Zealand forest estate will increase over the next 10 years, lifting to levels of up to 35 million m3 per year from the mid-2020s. Most of this increase will come from small-scale forest growers who established forests during the 1990s[3]. It is imperative that opportunities to reduce steep country harvesting costs continue to be investigated to ensure that these smaller scale forests are viable to harvest.

Personnel safety is also a key consideration in cable logging. Studies show that worker fatigue is experienced by all workers on site [4, 5] and fatigue is recognised as being one of the main safety issues within the forest industry. It has been found that workers who reported high levels of fatigue also reported higher rates of near miss incidents[6]. Some of the proposed solutions to the issue of fatigue are increased mechanisation and the utilisation of machinery with improved ergonomic conditions, resulting in comparatively lower fatigue rates.

One of the objectives of the PGP Steepland Harvesting programme is to monitor and investigate new yarder technology and developments from overseas that could offer cost efficiency and ergonomic benefits to New Zealand. As part of this objective, three new yarder models have been evaluated. The first was the Italian-built Valentini V1500 cable yarder operating in Italy[7], the second was the New Zealand-built Active 70 yarder using a Boman dropline carriage[8] and the third was the first Koller K602H yarder introduced to New Zealand in early 2015[9]. The aim of these evaluations was to investigate the cost-efficiency and ergonomic benefits arising from the introduction of this new technology.

The first study of the Koller K602H yarder was undertaken in February 2015 in small piece size Corsican pine in Mangatu Forest, near Gisborne. In that study the landing operation was controlled by the processor operator. Results showed that, in a single span configuration with an average piece size of 0.68 m^3, average haul volume of 1.84 m^3 and average haul distance of 217 m, productivity of 15.2 m^3/PMH was achieved. Indicative daily production was 113 m^3 per day.

The question remained however, how would the Koller K602H yarder perform in a more typical harvest area of radiata pine? This report summarises the follow-up to the earlier studies to assess the performance of the

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Koller K602H yarder working in bigger piece size radiata pine.

THE MACHINE

The Koller K602H is a trailer-mounted cable yarder built by Koller Forsttechnik GmbH of Austria (Figure 1).

Figure 1: Koller K602H yarder on site

The yarder has a 12-metre telescopic tower, 154 kW engine and weighs 15 tonnes. Drum capacities and line pull are given in Table 1.

Table 1: Koller yarder rope and drum capacity
****used during assessment***

Drum	Size (mm)	Capacity (m)	Line Pull (kN)
Skyline	22	720	95
Mainline	19*	291*	50
Haulback	12	1350	43
Strawline	6	1700	

The Koller K602H yarder has a number of features that are different from most yarders in New Zealand. These features include: a full remote control system for the breaker-outs and operator at the landing (requiring no yarder operator); semi-autonomous functionality of the motorised carriage; low gross weight allowing simpler transport; a turbo diesel engine that is highly fuel-efficient; and a built-in tension monitor that allows accurate pre-tensioning of the skyline.

In this study the yarder was matched with a Koller MSK 3 motorised slack pulling carriage fitted with two electronic chokers (Figure 2). The MSK carriage weighed 690 kg, and was powered by a 5.6 kW engine. The yarder was fully remote controlled, whereby both the landing operator and a breaker-out had radio control systems.

Figure 2: Koller MSK motorised slack pulling carriage

STUDY SITE

This study was carried out over five consecutive days from 27 February to 2 March, 2016 in a radiata pine plantation at Waikura Station, 20 km inland from Hicks Bay, East Cape, New Zealand. The forest was planted in 1978. No pre-harvest inventory data were available. A sample of trees was measured to provide an equation to estimate tree volume from measurement of large end diameter.

For the duration of the study only one skyline corridor was used. That corridor included two intermediate supports. The multi-span set up ran from the tower set at 10 metres, to the first 12-metre intermediate support around 55 metres away (at -9° slope) and then a further 140 metres to the lower 14 m high support (at -22° slope). The tower was raised by two metres and

the first intermediate support by one metre on the second day of the trial to increase clearance of logs in the chute and at the first intermediate support.

Breaking out Methods

Over the course of the study different breaker-out combinations were used. For the first three days, a single breaker-out only was used. During the first two days, the breaker-out cut large trees in half and set the chokers. No pre-setting of chokers was carried out because of the short average haul distances (33 m and 72 m). As the haul distance increased beyond 75 m the breaker-out began pre-setting chokers during the carriage return part of the cycle.

On Days 4 and 5, two breaker-outs were used. Given the carriage return was fully controlled by the Koller MultiMatik control system, the breaker-outs could concentrate on planning the next drag. The carriage had excellent slack pulling capability which allowed a 40-m lateral break-out corridor, allowing safe cut-to-length and pre-stropping to be undertaken while the carriage was returning automatically to the break-out position (outhaul). Both breaker-outs pulled slack when required even though one breaker-out could achieve this on his own. The pre-setting method was often used on days 3, 4 and 5 when average haul distances exceeded 100 m.

When two breaker-outs were used, one would cut large trees into manageable lengths and control the carriage, while the other set the choker (often one tree at a time) and pre-set a second choker for the next cycle if time permitted. If time did not allow pre-setting, the choker was left beside the next tree and pre-setting would occur as the carriage was returning to the break-out position. Where it was safe, pre-setting did occur during the latter part of the inhaul element as well. During in-haul the breaker-outs would retreat a safe distance in accordance with their safe retreat plan. *(FFR Note: Section 12.2.13 of the Approved Code of Practice for Safety and Health in Forest Operations (ACOP)[10] states: "Breaker-outs shall not enter the hook-on area until the 'stop' signal has been given or the carriage has stopped moving".)*

During the week of the study weather conditions were good, with intermittent light wind and very light rain showers. Effects of weather were not considered significant.

STUDY METHOD

Productivity Measurement

The productivity of the yarder was assessed by a time and motion study. Outhaul distance was captured by a GPS mounted on the carriage and checked by manually shooting the distance to the carriage using a range finder. The volume per cycle was estimated by the number, length and large end diameter of the stems and logs in each cycle. The butt diameter was measured by the breaker-out during four of the five days and estimated by an observer on the fifth day of the study. This information was used to estimate the volume per haul. The time to measure the butts was excluded from the productive cycle time.

Ergonomics Assessment

Heart rates of the breaker outs were recorded every five seconds using a strap-mounted pericardial heartbeat transmitter; which connected wirelessly to a wrist watch-mounted storage unit. This method was considered accurate and had minimal effect on the ability of workers to do their job effectively[5, 11, 12]. Indices were used to remove bias in heart rate data recording. In this study the "relative heart rate" indices were used. These have previously been found to be an effective method of assessing the physiological strain of forest workers. Common terms used in these indices are:

- Working heart rate (HRw) = Average heart beats per minute (bpm) over the day
- Maximum heart rate (HRmax) = 220 – age
- Resting heart rate (HRr) = the average heart rate value in a sitting position for a 10-min period.
- Relative heart rate at work (%HRR) = ((HRw – HRr) / (HRmax – HRr))*100

Multiple factors can contribute to work levels and productivity, other than just the machinery[13, 14]. Example factors include slope, roughness of terrain / obstacles and climatic conditions [5, 11, 14].

Cable yarders are usually very loud machines and prolonged exposure can lead to a number of health related issues, the most common being noise-induced hearing loss. The noise level of the yarder was measured in decibels. Data were collected using a Lutron SL-4033SD sound (decibel) monitor resting on the edge of the landing 12 metres from the yarder. The data were collected by taking the maximum sound volume (weighted) of the machine at two second

intervals over the period of the working day. The decibels were averaged across the collection days and then calculated at varying distances.

The noise monitor was also exposed to other operational noise that occurred on the landing, including the processor (Figure 3).

Figure 3: Other operational noise was generated near the decibel monitor.

The additional sources of noise would have had significant influence on the results, therefore periods when the processor was not working were used to supply accurate noise level readings of the yarder.

The Koller K602H built-in tension monitor was calibrated against the LIRO tension monitor used by University of Canterbury. The Koller tension monitor was found to be accurate to within 2% of the results showing on the LIRO monitor, and provided a high degree of confidence in its accuracy.

RESULTS AND DISCUSSION

Productivity Assessment

Over the five days of the study, an estimated total volume of 627 m^3 was extracted in 238 haul cycles over 19.6 productive machine hours (PMH). Daily productivity varied from 25 to 37 m^3/PMH, with an average productivity of 32.0 m^3/PMH being achieved (Table 2).

As discussed, due to the large tree size, trees were cut to length prior to extraction. For example, on Days 2, 3, and 4, 24% of all extracted pieces had been cut to length. On Day 5, 46% of the extracted pieces had been cut to length. Cutting to length added to the cycle time by as much as 10%. Of the 269 pieces hauled during the study, 56% were tree lengths, 28% were butt logs and 16% were tops. The average extracted piece size was 2.33m^3.

Table 2. Gross Production for the Study

Productive hours	19.6 PMH
Haul Cycles	238
Total Volume Production	627m^3
Total No. of Pieces	269
Average Extraction Distance	117m
Average Piece Size	2.33 m^3
Pieces per Cycle	1.13
Average Cycle Volume	2.63 m^3
Delay-free Cycle time	4.94 min
Hourly Productivity	31.94 m^3

The average number of pieces per cycle was 1.13, with two average sized pieces often being too large a payload. Given average piece size of 2.33 m^3, the average haul size was 2.63 m^3 per cycle. Estimated daily average haul size remained relatively constant, ranging from 2.52m^3 to 2.8m^3 (Table 3).

Table 3. Daily productivity for the 5-day study

Day	1	2	3	4	5
AHD (m)	33	72	101	133	187
Breaker outs	1 A	1 A	1 B	2 BC	2 AC
No. Cycles	23	30	53	73	59
Average cycle time (min)	4.2	5.5	5.2	4.3	6.1
Mean Haul Size (m^3)	2.52	2.80	2.76	2.64	2.58
Productivity (m^3/PMH)	36.0	30.5	31.9	36.8	25.4

The study captured extraction distances ranging from 20 to 220 metres, with an average extraction distance of 117 metres. Over the 5-day period wood in the corridor was extracted from the front to the back yielding increasing average haul distances (AHD) as shown in Table 3.

The skyline was set at 6% deflection, which is not uncommon for a multi-span setup where the skyline must be held reasonably tight so the carriage can ride up over the intermediate support jack.

The average cycle time was 4.94 minutes per cycle, ranging from daily average of 4.2 min/cycle on Day 1 (average haul distance of 33 m) to a daily average of 6.1 min/cycle on Day 5 (average haul distance of 187 m).

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As expected, the delay-free cycle time varied significantly with haul size and haul distance. A breakdown of cycle elements for Day 4 is provided in Table 4. Because of the changing work conditions, data for Day 4 are presented as being representative of performance where two breaker-outs were working, and the average extraction distance at 133 m was close to the average for the whole study.

Table 4. Haul Cycle Breakdown for Day 4 (2 Breaker-outs, AHD = 133m)

Element	Min	%
Outhaul and position carriage	0.77	18
Walk in, lower and pull rope	0.63	15
Hook on and walk out (pre-strop and cut/trim as required)	0.79	18
Breakout to skyline	0.59	14
Inhaul	1.18	27
Unhook	0.37	8
Total Cycle	4.33	100%

Carriage outhaul speed varied from 1.09 m/sec to 3.52 m/sec, averaging 2.46 m/sec. This compared to the average of 3.1 m/sec found in the earlier Valentini study[7]. Like the Valentini yarder, the Koller K602H's automated settings controlled the travel speed of the carriage when passing over the intermediate support jack.

The combined element time on Day 4 to walk in, lower strops, pull slack, hook on and walk out was very fast at only 1.42 min per cycle. This was due to the relatively easy slopes (-22 degrees from 55-200m haul distance) and the fact that some drags were pre-stropped. The ACOP Sections 12.2.8–12.2.26 state the preferred work practices for breaking out[10]. New yarders such as the automatic Koller K602H have features that result in safer operations, and that may necessitate a review of these preferred work practices. Examples include automated carriage return, full control of carriage and rope movement by the breaker-out during hook on, use of intermediate supports creating better lift, and the lower main line pull of the Koller K602H resulting in less hazard of trees swinging around if the drag digs in to the ground.

The average breakout time using two breaker outs was 0.59 min per cycle. Breakout time did not vary significantly with haul size or with different lead breaker-outs used, but was affected by haul distance. This was explained by the difficult tree layout where trees were bunched in a gully and carriage position was sometimes below the lower intermediate support. In the earlier Valentini study[7] average breakout time (which included time from carriage stop until inhaul start) was reported to be 4.43 min (using a single breaker out), as opposed to 2.0 min in this study (with two breaker outs).

Inhaul speed with the Koller ranged from 1.4 to 4.1 m/sec averaging 2.6 m/sec (days 3 and 4). Slower speeds appeared to be correlated with larger payloads.

Major operational delays occurred in the first two days, owing to rigging an intermediate support and mechanical damage to the intermediate support jack. This resulted in a low number of cycles completed. Delay time during the study was high resulting in machine utilisation of only 47%. This utilisation rate is below a typical New Zealand range of 65 to 70%[15].

The low utilisation rate was also due, to a lesser extent, to the crew still getting familiar with the new technology. It would be expected that, as the crew became more experienced, mechanical and operational delays would decrease, improving utilisation and overall system productivity.

Table 5. Comparison of Koller K602H study results with previous multispan studies

	Chile	Mangatu	Waikura
Productive hours/day	7.4	7.4	3.9
Average haul distance (m)	240m maximum	50	117
Average tree volume (m^3)	1.0	0.74	2.33
Average trees/haul	2.46	1.5	1.13
Average haul volume (m^3)	2.46	1.11	2.63
Average cycle time (min)	8.3	4.8	5.0
Average volume/day (m^3)	133	103	125

Results from this study at Waikura were compared to those from the previous FFR study of the Koller K602H in Mangatu in 2015[9], and with Chilean information on Koller yarders. It appears that daily production was comparable, despite the larger tree size and shorter haul distance of the Waikura study (Table 5).

System Cost

For this system there was a cost benefit advantage to using two breaker-outs. The use of two breaker-outs resulted in shorter delay-free cycle times. On Day 3, delay-free productivity was 31.9 m^3/PMH (using one breaker-out) and on Day 4 it was 36.8 m^3/PMH (with two breaker outs). At an estimated logging rate of \$34.96/m^3, the extra 4.9 m^3/PMH produced more than covered the cost of the extra worker, even at the low utilisation rate in this study.

Assuming the operational and mechanical delays experienced in this study could be reduced to achieve average yarder utilisation of at least 60%, resulting in a total of 5.0 productive hours per day, daily productivity of the Koller K602H, under the observed conditions, would increase to around 160 m^3/day.

A preferred logging system based around the Koller K602H yarder would include a processor/loader combination machine, using quick coupling technology being developed by FGR[16]. The costing and configuration for this system is outlined in Table 6.

Table 6. Single Koller yarder operation with a combination processor and loader.

One Koller 602H System	No	Hours	$/Day
MACHINERY			
Koller 602H	1	8	1,088
Cat 330 Excavator	0	0	0
Forwarder	0	0	0
Processor/Loader Combo	1	10	1,754
PERSONNEL			
Machine Operators	1	10	314
Logmaker/QC	1	8	286
Fallers	1	8	286
Breaker Outs	2	8	572
ADDITIONAL EXPENSES			
Vehicles, Training, Management			662
SUB-TOTAL			4,963
Profit allowance on non-staff items	15%		526
TOTAL DAILY RATE REQUIRED			5,489
Indicative Production			157
Indicative Rate			34.96

Incorporating quick coupling technology to enable only one processor/loader machine to be employed would result in expected logging rate of \$34.96/m^3 which is 8% lower than that calculated in the earlier FFR Koller study in 2015. This indicative rate is also 7% lower than the average yarder logging rate (\$37.50/tonne) from the 2015 benchmarking study of NZ yarder operations [1].

Tension Monitoring

Skyline tensions were recorded for 35 cycles. A typical 20-minute segment of tension data is shown in Figure 4.

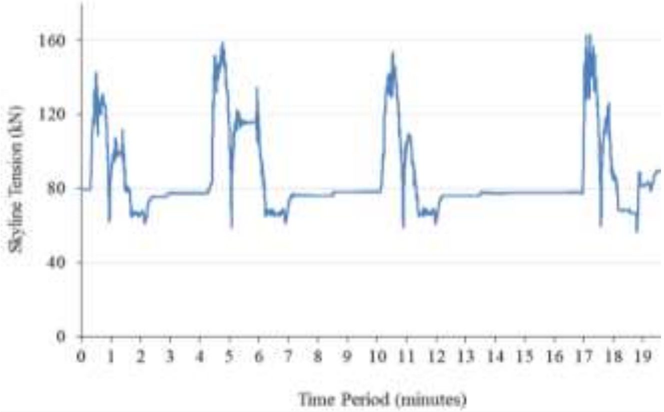

Figure 4: Example of Koller K602H tension monitoring data.

The skyline was 22 mm swaged with a minimum breaking load of 43 tonnes. Using a safety factor of 3, the safe working load (SWL) of the skyline was 14.3 tonnes [17]. The automatic skyline overload protection was factory-set to slip at 20 tonnes.

The average maximum tension per cycle recorded was 15.7 tonnes, indicating that the skyline tension could have been a production-limiting factor. However in this study the mainline pulling force was the limiting factor.

The skyline was pre-tensioned to 7 tonnes, and the tension increased to about 8 tonnes when the carriage was at mid-span. Pre-tensioning is required when using intermediate supports to ensure the carriage rides up over the jacks correctly. Tension increased rapidly during breakout and inhaul. A characteristic drop in tension was experienced when the carriage was near the intermediate support.

The maximum tension during inhaul was experienced only for very short periods, and typically at mid span. The overall recorded maximum of 18.0 tonnes equated to 42% of the breaking load. Of the 35 assessed cycles, 27 were over SWL with only eight cycles recorded under SWL. The average maximum tension for each cycle was 10% over safe working load and 19 of the 35 cycles (55%) were within two tonnes of the SWL. A possible solution to the issue of SWL overloading would be to use a 22-mm power swaged

skyline which would increase the SWL of the skyline to 17 tonnes.

A previous evaluation of the Valentini V1500[7] noted that where skyline tensions for intermediate support systems are monitored and shock loadings eliminated, it is feasible to run at higher than SWL tensions without damaging the skyline cable. That study also noted that a rule-of-thumb payload estimation for an intermediate support system is $^1/_6$ to $^1/_7$ of the SWL of the skyline. In this study, that would theoretically be between 2.0 and 2.4 tonnes. The estimated average haul size here was 2.6 tonnes, indicating that the system was being used effectively and payloads per cycle were maximised.

Noise level analysis

The decibel ratings for the yarder at varying distances are shown in Table 7. It was found that only if personnel were within a 2.5 metre range of the machine over extended time periods without protection would there be a significant risk of hearing damage[18].

Table 7. Estimated decibel ratings at various intervals from the yarder

Distance from Yarder (m)	*Volume (dB A)*	*Risk of hearing damage*
1.0	85	Significant
2.5	77	Moderate
5.0	70	Minimal
10.0	65	Minimal
20.0	50	Minimal

As a comparison, noise measurements from a Thunderbird TSY 255 yarder (including noise from the Talkie Tooter® system) were also measured and had a moderate danger zone (around 80 decibels) of 50 metres. As such, the Koller K602H yarder was judged to be a very quiet machine.

Heart rate data analysis

The head breaker-out wore the heart rate monitor for the full five days of the study. There were no issues with data collection resulting in over 35 hours of usable data. The breaker-out had a 'relative heart rate' score of 36.9 %, at the upper end of the 30%-40% range that indicates "prolonged continuous work" [5].

The breaker-outs worked hard and for prolonged periods over the time period of the study. There was insufficient evidence to indicate any differences in work rates between the breaker-outs assessed. Higher workloads were expected when the breaker-out was working alone, but the two days where two breaker-outs were present were split above and below the overall single breaker-out average. When choker-setter work rates were compared with previous studies [5, 12], it was found that there were no advantages in terms of reduced work rate with using a motorised carriage.

CONCLUSION

The Koller K602H is the first of a new class of small remote controlled semi-automated yarders in New Zealand. The delay-free productivity rate at 32.0 m^3 / PMH indicates that this machine has potential in some New Zealand forests where extracted piece size is not too large to limit the machine. The practice of cutting to length on slopes is unsafe due to risks of sudden log movement and is not a recommended practice, therefore the Koller K602H is suited to smaller tree size where this is not required.

Given that the Koller yarder has semi-automated functions, labour requirements were low. The use of a motorised slack pulling carriage showed no reduction in workload for choker-setters compared with the North Bend system. Heart-rate data collected showed that the work is labour intensive and is in the "prolonged continuous work" scale. With further development of a grapple extraction system to operate over intermediate supports, the need for a breakerout could be reduced.

The Koller K602H has a modern, quiet engine compared to older yarders, but people working within 2.5 metres should still wear hearing protection to avoid noise-induced hearing loss.

The tension monitor on the Koller K602H proved to be highly accurate and the average maximum tension for each cycle was 10% over safe working load. This suggested that the system was being used effectively and payloads per cycle were maximised.

During this study, low machine utilisation (47%) was the reason for the low average daily production of only 125 m^3 per day (15.0 m^3 per scheduled machine hour). The low utilisation rate was due to delays in rigging an intermediate support tree, and damage to the intermediate support jack. To a lesser extent the low utilisation rate was due to the crew still getting familiar with the new technology and learning the machine's capability. It is expected that if machine utilisation improved to achieve an average of 60% (typical of most New Zealand hauler operations), daily production would increase to 160 m^3/day, at a logging rate of \$34.96 /m^3, which was lower than the average NZ hauler rate in 2015. This suggests that a Koller yarder system could be cost-competitive with many NZ yarder operations in similar conditions.

The other advantages of the Koller K602H yarder, such as remote control, smaller crew size, and lower capital cost, mean that the Koller yarder has potential for harvesting small steep country forests with difficult access, as long as extracted piece size is not too large to limit the machine.

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