Original scientific paper

Productivity Analysis of an Un-Guyed Integrated Yarder-Processor with Running Skyline

Bruce Talbot, Giovanna Ottaviani Aalmo, Karl Stampfer

Abstract

An excavator-based integrated yarder-processor was evaluated in a clearfelling in central Norway. The machine is unique because, as it uses a running skyline setup, yarding and processing cannot take place simultaneously as is the case with many European integrated tower yarders. Felling productivity was 10.6 m^3 $E_{15}h^{-1}$, yarding 9.2 m^3 $E_{15}h^{-1}$ and processing 10.9 m^3 $E_{15}h^{-1}$. Given that yarding and processing take place alternately accounting for 54% and 46% of a system hour, the overall system productivity was 4.9 m^3 $E_{15}h^{-1}$ (processed and stacked). The processing rate was approximately 30% of what is achieved by single grip harvesters, indicating the effect of space limitations, a possible over-dimensioned processing head, and the need to simplify the assortment list under such conditions. An increase in processing productivity would require a second feller-chokersetter in the crew, although neither would then be used to full capacity. Un-choking alone accounted for 19% of the yarding cycle time and might be reduced by applying self-releasing chokers. System productivity needs to be increased by 30–50% to make it competitive. Much of this could be achieved simply by deploying the machine in stands with larger mean tree volumes than those observed (0.27 m^3).

Keywords: steep terrain, timber harvesting, cable yarding, un-guyed yarder

1. Introduction

Excavator-based forest machines are an alternative to purpose built machines and, where terrain allows, can be used in applications ranging from drainage maintenance through site preparation and planting, as tracked harvesters, roadside processors, stump harvesters and cable yarders (Johansson 1997). Their popularity can likely be explained by their global availability, low cost, robustness, ease of operation and large interface with other sectors, such as earth moving, construction, and road building. Cable yarding is a specific application of excavators in forestry, but is widely applied in Japan (Yoshimura and Noba 2013) and gaining ground in countries like the UK (Tuer et al. 2013), Ireland (Devlin and Klvac 2013), South Africa (McEwan et al. 2013) and Canada (Gingras 2013). The mass of the base machine and support of the boom arm as an outrigger allow for excavator based yarders to operate un-guyed.

Un-guyed yarders are considered to offer a number of advantages under conditions of (i) space restrictions: mobility on the landing during operation to allow for trucks to pass, to prevent congestion by moving continuously away from tree piles or log stacks or obstructions experienced in the corridor, un-guyed yarders allow for the forest road to effectively be used as a continuous landing, (ii) Short corridors or low volume densities: only the tail-spar needs to be rigged, un-guyed yarders have a lower setup time and therewith a competitive advantage on shorter corridors where higher rigging times are not justified by the limited volume extracted, and (iii) local and seasonal availability: excavators are relatively low cost and readily available base machines that have a range of applications and can be used seasonally for forest work by e.g. farmers (Johansson 1997).

The configuration and functionality of un-guyed excavator based yarders varies considerably. Each concept offers benefits and restrictions pertaining to complexity, versatility, stability, productivity and economy. Base machines range from c. 15 to 40 tonnes. Winches range from single drum to 3-drum systems, both mechanically and hydraulically driven. Some use a block mounted on the boom for lift, while others are fitted with towers of varying height, mounted on the machine, the boom, or the boom tip. Some of the configurations retain the bucket for stability, others have replaced this with a timber grapple, while yet others have a felling/processing head attached to the boom tip. Excavator-based yarders can be distinguished from other yarders built on similar undercarriages, in that part or all of the boom is retained and not replaced with a gantry setup as are the Madill type yarders.

Torgersen and Lisland (2002) provided an overview of the perceived advantages and disadvantages of these configurations in considering their potential application in Norway. Excavator-based yarders are considered to be well suited to the inland conditions in Norway with small crews (2–3 people), small trees in (0.2–0.4 m^3 per stem), generally small work objects (c. 1–3 ha.) and with low harvesting volumes (150–220 m^3 ha^{-1}). There is a need to develop more versatile harvesting systems in Norway where some 150 million m^3 of timber is mature or maturing on slopes with an inclination steeper than 33% (Larsson and Hylen 2007) equating to the volume of 15 national annual cuts.

Recent cable yarding productivity studies of relevance include Spinelli et al. (2010) who studied two small-scale units in hardwood stands the Apennine's, Ghaffariyan et al. (2009) who developed production equations for two tower yarders in predominantly fir stands in Alpine conditions, and Zimbalatti and Proto (2009) who report on productivity rates for three different tower yarders extracting timber for firewood production in Calabria. However, apart from Torgersen and Lisland (2002), only limited work has been published on the productivity rates achieved by this machine genre. Largo et al. (2004) studied a Timbco feller-buncher based yarder and a Caterpillar excavator based yarder in thinning operations in Idaho. Both were fitted with two-drum winches and used in a live, gravity system, and operated with 2-man crews. The work of Stampfer et al. (2006) is relevant in that they studied installation times for tower yarders, an important potential area for time saving on un-guyed yarders.

The lack of literature addressing this specific topic indicates that no previous productivity studies have been published for this type of fully integrated machine. As the use of excavator-based yarders appears to be on the increase globally, results from the present work might be useful in identifying areas for improvement or application.

1.1 Aim

The aim of the present paper was to analyze the productivity levels achieved by a new fully integrated yarder-processor combination operating in a clear cut in the inland forest region of Norway.

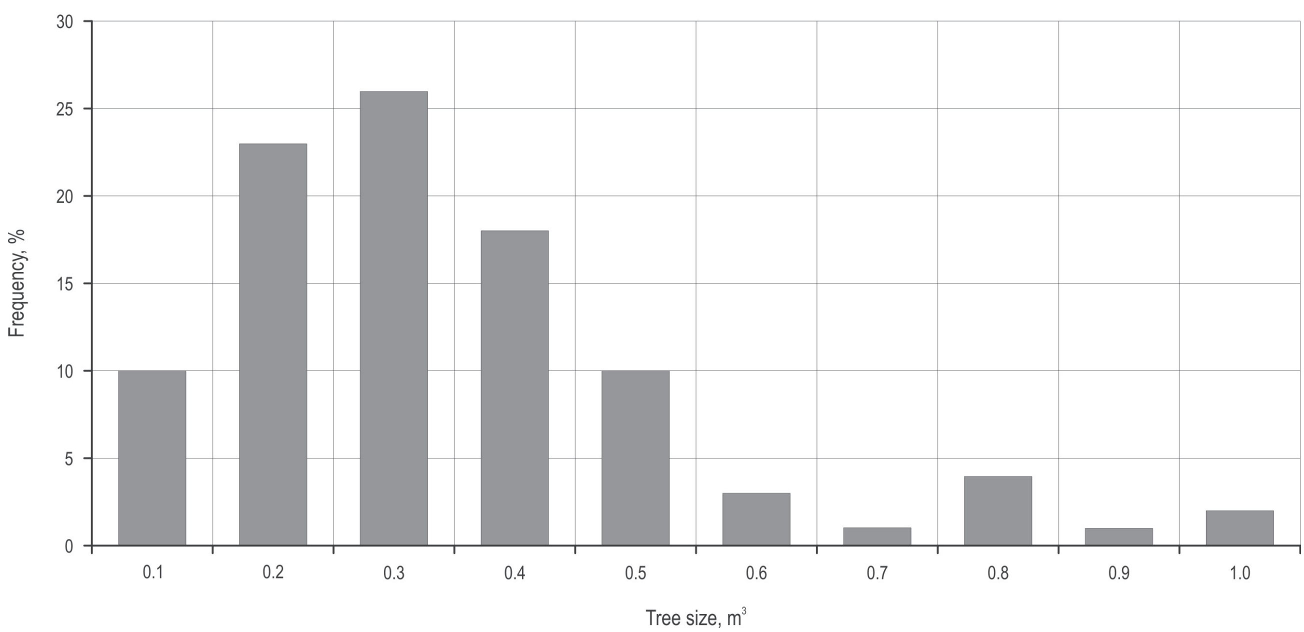

Fig. 1 Distribution of trees to volume intervals

2. Materials and methods

2.1 Site information and work conditions

Studies were carried out over 4 days in a mixed Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) stand located in the upper Gudbrandsdalen valley in central Norway (UTM N 6,835,676 m, E 531,062 m). Working conditions on the site could be classified as good, an even and moderate north facing slope of ~43% with no notable surface obstacles. The diameters of 98 trees were measured, and diameter-height relationships of an additional 20 trees were measured in calculating single tree volumes. The mean tree volume was 0.27 m^3 (s.d. 0.21), while the smallest was 0.04 m^3 and the largest 1.12 m^3 (Fig. 1). For the time study, trees were classified into 3 size classes with the following mid volumes; (1) small 0.17 m^3, (2) medium 0.31 m^3 and (3) large 0.56 m^3. Stumps in three randomly located circular plots (r=10 m) were counted after harvesting, indicating a stand density of 610 stems ha^{-1} and a stand volume of roughly 140 m^3 ha^{-1}, a poor stand equating to a site index$_{40}$ of 11 m (Tveite 1977). The operation studied was a clearcut. Weather conditions were warm and dry.

2.2 Technical machine data

The machine studied was an excavator-based yarder developed by Zöggeler Forsttechnik in Austria (Fig. 2), which is unique in that it is fully integrated with both yarding and processing capability, but unlike similar tower yarders, these operations cannot take place simultaneously. The hydraulic winch (Table 1) has 3 in-line drums mounted on the boom, each fitted with auto-tensioning, which allows for slack to be spent or taken up continuously while slewing during processing or stacking without pulling up the tail spar or applying undue tension on the boom (Fig. 3). The lightweight carriage uses the slackpulling line in feeding the mainline out to be used as a skid line.

The winch was mounted on a 21 t Doosan DX210W wheeled excavator, stabilized with a dozer blade in the

Table 1 Technical information on the winch

Manufacturer	Zöggeler Forsttechnikk (http://www.zoeggeler.at/)
Drums	3, hydrostatically driven with auto-tensioning
Haulback line	500 m, 11 mm
Mainline	250 m, 11 mm
Slackpulling line	500 m, 6 mm (also used as rigging winch)
Line speed	Max 4 m s^{-1}
Carriage	Zöggeler carriage with slackpulling capacity
Carriage mass	150 kg

Fig. 2 The Zöggeler yarder at work on the study site

Table 2 Technical information on the base machine and processing head

Base machine		Processing head	
Model	Doosan DX210W	Model	Zöggeler ZBH58
Mass	20,500 kg	Mass	1,480 kg
Motor	Doosan 6 cyl. 6 liter	Maximum cut diameter	70 cm
Rated power (gross)	127 kW at 2000 rpm	Optimal oil supply	300 l min^{-1}
Hydraulic pumps	2x232 l min^{-1}	Loading grapple	150 cm/0.7 m^3

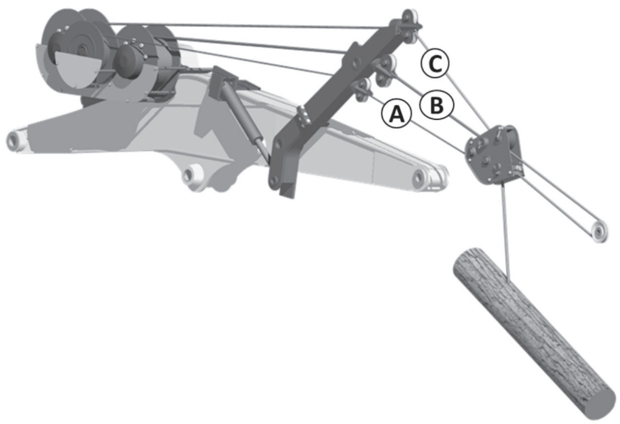

Fig. 3 Illustration of the 3-drum inline winch and hydraulically lifted tower with butterfly pulleys mounted on the boom, as well as the (A) slackpulling line, (B) mainline and (C) haulback lines (Copyright Zöggeler Forsttechnik)

front and outrigger at the rear. The excavator is fitted with a two-piece boom, and a telescopic replacement for the boom arm. A specially designed processing head with loading arms (Zöggeler ZBH58) was fitted to the boom arm for processing the trees and stacking logs (Table 2).

2.3 Time and productivity studies

The machine yarded uphill in a running skyline setup. Corridor length was short, varying between 80 and 120 m. The operation involved a 2-man crew, one machine operator and one feller-chokersetter, with multiple years of experience on tower yarders, but only around 4 months of operating experience on the Zöggeler machine. The standard work method adopted by the crew was studied. This alternated between yarding (involving both crew members) and processing (machine operator) with simultaneous felling (feller-chokersetter). The switch between work functions took place for every 5–7 loads (11–16 trees).

Time studies were carried out using Haglöf SDI® software running in a Windows CE® environment on an Allegro MX datalogger from Juniper Systems™, which allows for continuous recording at the centiminute (min × 10^{-2}) level. Work elements and variables measured for each operation are provided in Table 3 in the results section to avoid duplication. The number of trees in each size class was recorded for each load. Estimates of haul-out distance (distance carriage travels into the stand) were calibrated intermittently using a laser range finder sighting back to the base machine. Lateral distance was estimated visually as the time keeper worked in close proximity to the feller-chokersetter.

After chokersetting and yarding, felling (motor-manual) and processing (mechanized) took place simultaneously and were studied individually. Felling alternated with chokersetting approximately every 20–25 minutes and so provided the feller-chokersetter with a varying workload over the day. Felling cycles started and ended when the tree hit the ground, and included elements such as moving, clearing underbrush, and brushing low branches (Table 3). Felling times for 217 trees were included in the final analysis.

Processing was recorded at tree level but time for the processing of individual logs within each tree was also recorded. Processing commenced when the processing head took hold of a new tree from the landing, and included other functionality such as the handling of residues, sorting, stacking and clearing the landing. Processing times for 254 trees and 745 logs were included in the final analysis.

Down-rigging, moving and rigging of new corridors was measured for 3 moves using wristwatch time. To minimize waiting time on the yarder, only the centerline of the new corridor was felled for a new rigging, the remaining trees were felled during normal operation. Time study data was cleaned of outliers, the distributions of individual time elements checked, and the regression models were developed and adapted using *R* statistical software.

3. Results

Results are presented separately for each of the 3 discrete operations: felling, yarding, and processing. Mean E_{15} times were 91.5 s tree^{-1} for felling, 240 s cycle^{-1} for yarding, and 88.3 s tree^{-1} for processing (Table 3). For felling, cutting out the felling notch and performing the felling cut was the single most time consuming element, at c. 36 s tree^{-1}. Values are here averaged out over all effective observations and can therefore appear shorter than their actual duration when occurring – e.g. the felling wedge was used 99 times out of 217 observations with a mean of 24.7 s per time used, but 11.3 s per observation mean. Felling productivity was 10.6 m^3 E_{15}h^{-1}.

For yarding, mean cycle time was 240 E_{15}s and mean extraction distance 75.4 m, requiring 27 s for the outhaul and twice that for the inhaul under load, as can be seen in the simple regression on time for hauling-out empty and hauling-in under load (carriage speed 1.67 ms^{-1}) in Fig. 4. At 42 s per load, un-choking was the second highest single time element after hauling in. Overall yarding productivity was 9.2 m^3 E_{15}h^{-1}.

Table 3 Means and standard deviations (in parentheses) for all work elements and numerical variables measured in the field study

Felling (n=217)		Yarding (n=149)		Processing (n=254)	
Move to tree, s	18.3 (16.2)	Haul-out, s	27.2 (8.7)	Prepare, s	17.1 (14.8)
		Haul distance, m	75.4 (28.7)		
Clear brush, s	4.4 (6.6)	Lateral-out, s	23.2 (9.6)	Process logs, s	45.0 (25.4)
		Lateral distance, m	6.5 (3.9)	Logs per tree, n	2.9 (1.4)
Prepare, s	11.4 (15.9)	Choke, s	24.8 (14.7)	Residue handling, s	2.8 (2.7)
		Trees per load, n*	2.27 (0.99)		
Cut, s	35.9 (22.8)	Lateral-in**, s	35.5 (18.1)	Stacking logs, s	17.6 (45.1)
Wedge, s	11.3 (8.6)	Haul-in, s	58.7 (24.9)		
		Un-choke, s	42.2 (11.2)		
Time tree^{-1}, E_0s	81.3 (70.2)	Time load^{-1}, E_0s	212 (59.8)	Time tree^{-1}, E_0s	82.5 (109.5)
Delay time, s	10.2 (56.3)	Delay time, s	27.8 (113)	Delay time, s	5.8 (5.3)
Time tree^{-1}, E_{15} s	91.5 (118.5)	Time load^{-1}, E_{15} s	240 (131.6)	Time tree^{-1}, E_{15}s	88.3 (120.9)
Trees, E_0 hr^{-1}	44.3	Trees, E_0 h^{-1}	38.6	Trees, E_0 h^{-1}	43.6
Prod. m^3, E_0 h^{-1}	11.9	Prod. m^3, E_0 h^{-1}	10.4	Prod. m^3, E_0 h^{-1}	11.7
Trees, E_{15}h^{-1}	39.3	Trees, E_{15}h^{-1}	34	Trees, E_{15}h^{-1}	40.8
Prod. m^3, E_{15}h^{-1}	10.6	Prod. m^3, E_{15}h^{-1}	9.2	Prod. m^3, E_{15}h^{-1}	10.9

* Movement between multiple trees during choking was accrued to lateral-out time

** Lateral-in is not a discrete element when winching with a running skyline as the load is hauled tangentially toward the yarder, and not to the corridor centerline first. In this study, lateral-in was used to record the break-out process, i.e. the time taken to get the load into motion toward the tower, thereby maintaining integrity of the distance based haul-in component

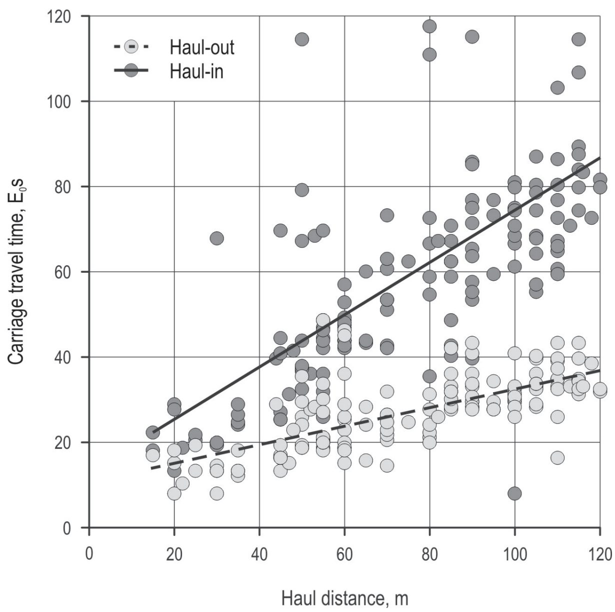

Fig. 4 Carriage travel time as a function of distance, where haul-in is travelling under load toward the yarder, and haul-out is travelling empty out into the stand

For processing, it took around 17 s to take hold of the tree, get it into position and dress the butt-end when necessary, and a further 45 s on average to process the logs. Sorting logs into the correct stacks was time consuming, adding another 18 s per tree. Processing productivity was relatively low at 10.9 m^3 E_{15}h^{-1}, but highly dependent on tree and log size. Fig. 5 shows how the processing time per log is relatively constant, while the productivity in m^3 E_0h^{-1} decreases exponentially. Here the common preparation time per tree is distributed to the logs by their volume proportion. Time elements associated with processing, such as stacking and handling biomass, are not included in Fig. 5.

Time consumption models were developed against effective time (ET) per unit. Various models were tested and those reported here were selected on their goodness of fit and F-value.

3.1 Felling

Only two independent variables could be included in the effective time consumption model for felling:

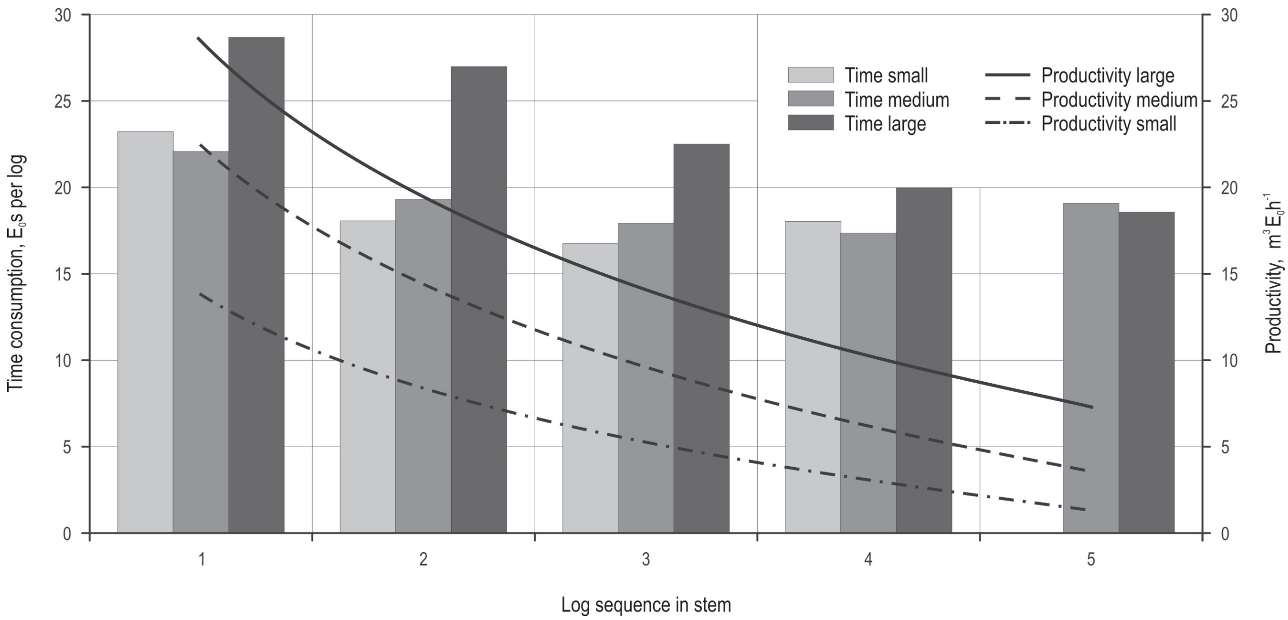

Fig. 5 Processing time (E_0s) per log, by tree size category and log sequence in the stem. The lines represent logarithmic approximations of processing productivity rates achieved by tree size and log sequence, as read against the right hand vertical axis in m^3 $E_0h^{-1}$is travelling under load toward the yarder, and haul-out is travelling empty out into the stand

TS, a categorical variable explaining the tree size classes and *WDG*, a binary variable indicating whether a wedge was used for directional felling or not. The general model to predict effective time consumption for felling per tree (ET_{fell}) is given by equation 1, where β_0 is the estimate of the intercept and $\beta_{1\text{–}2}$ are the coefficients to be estimated. The model assumptions were checked using a full residual analysis:

$$ET_{\text{fell}} \sim \beta_0 + \beta_1 TS + \beta_2 WDG + \varepsilon \qquad (1)$$

Regression results for the effective time consumption model for felling are reported in Table 4.

This regression model produced $R^2 = 0.35$, F (3,162)= =29.8, p<0.001. All independent variables were significant and positive confirming that the effective time to implement the felling operation increases with increasing tree sizes and with the use of the wedge. The low R^2 is likely due to the fact that the moving distance between the trees was not recorded, but accounted for a relatively large part of the effective time.

Table 4 Regression model parameters for felling

	Coefficients	Standard error	*t* stat	*P* value
Intercept β_0	43.09	4.89	8.80	<0.001***
Treesize 2 β_1	16.17	7.28	2.22	<0.05**
Treesize 3 β_1	42.34	12.01	3.52	<0.001***
Wedge (1) β_2	41.59	7.28	5.71	<0.001***
R-squared	0.35			
Adjusted *R*-squared	0.34			
F-statistic	29.8 (on 6 and 162 DF)			<0.001
No. observations	217			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 5 Regression model parameters for yarding

	Coefficients	Standard error	*t* stat	*P* value
Intercept β_0	73.6	12.78	5.76	<0.001***
Hauling Distance β_1	1.17	0.11	10.35	<0.001***
Lateral Distance β_2	1.61	0.82	1.97	<0.01.
Trees/Cycle β_3	19.19	3.28	5.85	<0.001***
R-squared	0.56			
Adjusted *R*-squared	0.55			
F-statistic	51.59 (on 3 and 121 DF)			<0.001
No. observations	149			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

3.2 Yarding

The general model for predicting the effective time for yarding was given by equation 2 as:

$$ET_{\mathrm{yard}} \sim \beta_0 + \beta_1 HD + \beta_2 LatDist + \beta_3 TC + \varepsilon \qquad (2)$$

Where ET_{yard} is the effective time for yarding, β_0 estimates the intercept and $\beta_{1\text{–}3}$ are the coefficients to be estimated, *HD* is the haul distance, *LD* is the lateral distance and *TC* is the number of trees per cycle. The results for this multiple linear regression model are given in Table 5.

The regression model yields an adjusted R^2 of 0.55, F (3,121)=51.59, p<0.001. Results show that the variable lateral distance was significant at a 10% level, while the other variables were all statistically significant at 1%. All coefficients were positive, confirming the positive correlation between time needed to perform the yarding task and the distances of the trees yarded from the tower and the line in addition to the number of tree parts of each load.

3.3 Processing

The time consumption prediction model for processing that best fitted the data consisted of a categorical variable representing the tree size *TS* and the number of logs obtained for each tree, *LOGN* (equation 3). β_0 is the estimate of the intercept and $\beta_{1\text{–}2}$ are the coefficients to be estimated.

$$ET_{\mathrm{proc}} \sim \beta_0 + \beta_1 TS + \beta_2 LOGN + \varepsilon \qquad (3)$$

Analysis of the residual plots indicated no systematic pattern and the underlying assumptions for regression were supported. The coefficients, all significant, are also all positive following the expected result of an effective time increase with increasing tree sizes and number of logs obtained per tree. Note that time for sorting and stacking logs, and handling biomass are not included in this model.

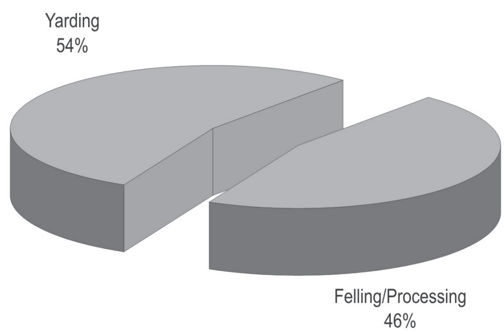

Fig. 6 Distribution of the system hour to yarding, and the slowest of processing/felling

3.4 System performance

Table 3 showed the time consumption for each work phase individually. As the machine cannot yard and process simultaneously, system productivity is limited by the least productive work phase. Each system hour was made up of yarding (54%) and the slower of felling or processing (46%), which in this case are almost identical at E_{15} time (Fig. 6). The resultant system productivity was 4.9 m^3 $E_{15}h^{-1}$. Relocation, rigging of the tail spar and corridor changes (it took roughly 2.5 h with 1 person) are not included in the E_{15}h.

4. Discussion

A fully integrated machine configuration such as this that cannot yard and process simultaneously is

Table 6 Regression model parameters for processing

	Coefficients	Standard error	*t* stat	*P* value
Intercept β_0	19.07	3.31	5.94	<0.001***
Treesize 2 β_1	6.39	3.407	1.88	<0.1.
Treesize 3 β_1	30.26	6.07	4.98	<0.001***
Number of logs/tree β_2	12.80	1.21	10.16	<0.001***
R-squared	0.52			
Adjusted R-squared	0.51			
F-statistic	91.5 (on 3 and 250 DF)			<0.001
No. observations	254			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

restricted by the weakest performing work phase. Felling productivity should largely coincide with processing to avoid operational delays. If unavoidable, it is preferable that delays befall the feller-chokersetter as that represents only c. 20% of the total system cost, and because such a delay implies rest time for this worker.

As a yarder, the machine showed good performance rates. Cycle times were short, some 240 E_{15}s on average (15 turns per hour), partially due to the short corridor lengths, limited lateral yarding, and the fact that the running skyline configuration makes the skidline immediately available to the chokersetter. The winch is powerful enough to yard larger loads than the 0.61 m^3 observed, and this would significantly improve productivity, but the chokers were well utilized at 2.3 trees on average, meaning that larger loads should come from larger trees. Roughly 19% of the yarding cycle time was used for unchoking, and this required the operator to climb up and down from the cab frequently, not without some risk. Research suggests that the use of self-releasing chokers could be useful in a setting such as this (Stampfer et al. 2010).

While felling and yarding are relatively effective, processing at 10.9 m^3 E_{15} h^{-1} is considerably slower than that for single grip harvesters. Gerasimov et al. (2012) found mean productivities of 31.3 m^3 $E_{15}h^{-1}$ during processing of trees of 0.16–0.30 m^3 and 46.1 m^3 per processing machine hour for stem volumes ranging between 0.31 and 0.5 m^3, in a study including over 4 million trees. This is roughly 3 times higher than the processing productivity observed in this study. While processing is somewhat constrained by the working position and limited space available to the yarder, this considerable gap can likely only be explained by the operator and processing head, which might be better suited to larger trees found in central Europe. The operator was highly skilled on the Konrad Woody 60™ processing head, but the controls for the Zöggeler head are configured differently and the operator might have required a longer period of adaption. An increase in processing speed would require another worker in the system as the feller appears to be working near maximum speed. However, a second feller-chokersetter would only be partly employed. An increase in mean tree size would likely provide the easiest path to increasing system productivity, especially with regard to processing.

The system hour consisted of 54% yarding and 46% processing/felling. With their similar machine, Torgersen and Lisland (2002) found the opposite distribution of 41–59%, probably as yarding was carried out over longer distances and the processor was more rudimentary (i.e. stroke delimber). However, their results at 6.2 m^3 E_0 h^{-1} sorted at roadside, were similar with those presented in this study.

Fig. 7 shows the influence of an increase or decrease in yarding or processing/felling productivity on overall system productivity. It illustrates how considerable increases in either or both dimensions are required in making marginal increases in system productivity.

Rigging was generally handled by the feller alone. The machine operator used the time to clean up on the landing, and mark timber piles for different customers. Corridors were short (80–120 m), no intermediate supports were used, all corridors were for uphill yarding, and the low cable tensions during operations allowed for light equipment and limited efforts on tail spar rigging. Most of the 2.5 h rigging time involved felling the centreline, and so was productive. By comparison, Stampfer et al. (2006) show how a small tower yarder working under similar conditions would require roughly 5 h installation time with a crew of 2. In their study of two non-guyed yarders in Idaho, Largo et al. (2004) report corridor changes of as low as 30 minutes.

Detailed system costs were not calculated, but estimates indicate required hourly prices of roughly

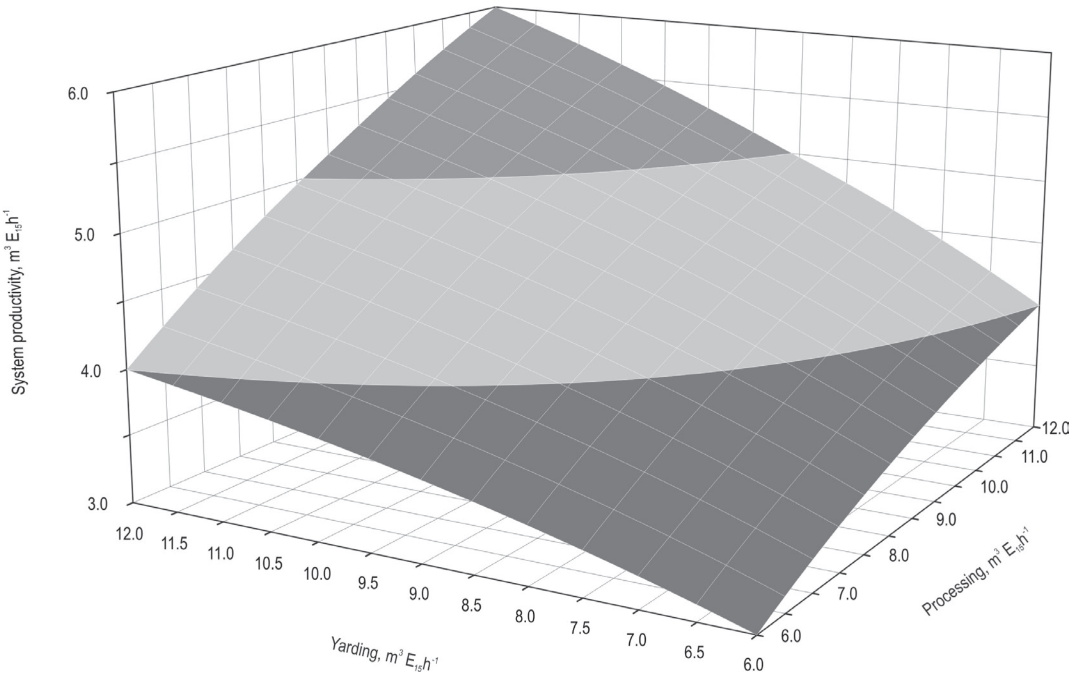

Fig. 7 Sensitivity analysis showing potential system productivity in relation to relative increases or decreases in yarding or processing/felling productivity

US$ 200 for the machine and operator, US$ 45 for the feller-chokersetter, including the chainsaw and all social on-costs (1 US$=6.12 NOK or 0.74 EUR). At a cost of roughly US$ 245 and a productivity of 4.9 m^3 $E_{15}h^{-1}$, the system is some way from being profitable in the present application, but is currently applied in areas with subsidies for special harvesting conditions. System productivity would need to be raised by 30–50% or the capital outlay reduced, to make the machine competitive in the free market. Opportunities for achieving this might include using a cheaper, reconditioned base machine, deploying the machine in stands with larger mean tree sizes, increasing operator productivity in processing through training and simplifying the somewhat complex number of assortments made.

5. Conclusions

The single machine system works well in terms of balance with a 2-man crew, but system productivity remains too low. The simplest method of increasing productivity while maintaining balance would be to deploy the machine in stands with slightly larger trees. Processing rate was approximately 30% of that of a single grip harvester in similar tree sizes, and is the main bottleneck to increased system performance. A higher processing rate would result in the need for a second worker in the field, as the feller already works at or near the maximum rate. With two workers in-field, neither would be fully employed. While this may still be economically beneficial, even given the high cost of workers in Norway, an important motivation for purchasing this system was the fact that it could be operated by a 2-man team.

To fully understand the potential of this interesting machine concept, more studies under varying conditions would be required. A full system analysis would also be required considering the costs, workload and productivity of a second man in the field and the separation of the yarding and processing functionality to two base machines.

Acknowledgements

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