Forest Science and Technology

ISSN: 2158-0103 (Print) 2158-0715 (Online) Journal homepage: www.tandfonline.com/journals/tfst20

Productivity and cost of a small-scale cable yarder in an uphill and downhill area: a case study in South Korea

Eunjai Lee, Sangjun Im & Sang-Kyun Han

FOREST SCIENCE AND TECHNOLOGY, 2018
E-ISSN 2158-0715, VOL. 14, NO. 1, 16–22
https://doi.org/10.1080/21580103.2017.1409662

Productivity and cost of a small-scale cable yarder in an uphill and downhill area: a case study in South Korea

Eunjai Lee[a], Sangjun Im[a,b] and Sang-Kyun Han[c]

[a]Department of Forest Sciences, Seoul National University, Seoul 08826, Republic of South Korea; [b]Department of Forest Sciences and Research Institute of Agriculture and Life Sciences, Seoul National University, Seoul 08826, Republic of South Korea; [c]Department of Forestry and Landscape Architecture, Korea National College of Agriculture and Fisheries, Jeonju 54874, Republic of South Korea

ABSTRACT

Tree diameter, topography, and stand accessibility have been major factors to consider when selecting the optimal equipment to extract logs from stump to landing area. In Korea, forest land has 6.4 million ha of forest, comprising 64% of its total land area. Small and medium (15–30 cm in diameter at breast height [DBH]) size of trees located on steep slopes (> 30°) is approximately 80% of total forest area. Therefore, there has been an increasing interest in the application of a small-scale cable yarding system. We performed uphill and downhill yarding experiments using an 80 hp farm tractor mounted tower yarder (HAM300) to evaluate productivities and costs associated with primary transportation of tree length logs in mixed conifer stands. In addition, sensitivity analyses were performed to find the effects of different yarding directions and distances on yarding productivities and costs. Results showed that uphill and downhill yarding productivities were 9.04 m^3/PMH (Productivity Machine Hours) and 7.87 m^3/PMH at a cost of US$9.06 and US$10.04/m^3, respectively. The yarding direction greatly affected productivity and cost: decreasing productivity may be significantly affected by working conditions. Our results support the effectiveness of an HAM300 yarder in extracting logs for small-scale cable yarding operations.

ARTICLE HISTORY
Received 25 September 2017
Accepted 22 November 2017

KEYWORDS
Farm tractor; HAM300; mixed conifer stand; steep slope; uphill and downhill yarding

1. Introduction

Determining the appropriate harvesting system relies on an understanding of many factors including tree size, harvest site characteristics (e.g. slope and soil), extraction (e.g. skidding/yarding) distance, machine availability and capabilities, and operator experience and motivation (Kellogg et al. 1992; Parker and Bowers 2006; Ghaffariyan and Brown 2013; Hiesl and Benjamin 2013). In particular, selecting the optimal cable yarding system and machinary on steep slopes is essential to improve machine productivity and work safety, while reducing harvesting costs (Hisel and Benjamin 2013).

A small-scale harvesting system has been used in timber harvesting in some countries (i.e. UK, Germany, Austria, Switzerland, Japan, and Iran) (Akay 2005; Jourgholami 2012, 2014; Yu et al 2016). As an effective log extraction, a farm tractor (at least 60 kW on power take-off [PTO]) equipped with a tower yarder is exclusively used for small-scale cable yarding operations in small forests (<40 ha) on steep slopes (>30%) (Visser and Stampfer 1998; Wilhoit and Rummer 1999; Updegraff and Blinn 2000; Russel and Mortimer 2005). This technology is preferred since it has economic benefits for tree or log management activities (Wilhoit and Rummer 1999; Harrison et al. 2002; Akay 2005; Yu et al. 2016). For example, a farm tractor system has lower initial and operating costs compared with a large-scale mechanized system (Wilhoit and Rummer 1999; Akay 2005). A small-scale cable yarder can also access harvest sites relatively easily (Updegraff and Blinn 2000), and can be applied in uphill and downhill hauling directions (Marenče and Krč 2016). However, a farm tractor is less suitable for demanding forest working conditions such as hydraulic pump capacity, and drawbar height and weight distribution ratio (Bjerkelund 1994; Sennblad 1995; Russel and Mortimer 2005). Nevertheless, these machines have been modified to be useful because they produce high-quality end values at a reasonable cost, and result in much lower soil impacts compared to ground-based harvesting systems (Russel and Mortimer 2005; Stanczykiewicz et al. 2015). Thus, small-scale cable yarding operations have been successful in assisting small forest owners as the most economically feasible options for yarding logs, particularly for small forests with homogeneous stands of tree management activities, which improves productivity and cost (Harrison et al. 2002; Yu et al. 2016).

In South Korea (Korea), forests cover 64% of the total land area, of which 80% are on slopes greater than 30° (Yun 2009). Small and medium diameter trees (between 10 cm and 30 cm) account for 80% to 90% of total forest (Park et al. 2013; Seo et al. 2015). The most common (>90%) extraction method has been based mainly on the use of small-shovel (5 metric ton weight excavator equipped with a log grapple) but cable yarding systems have been still in the early stage, even though there is steep terrains (Figure 1; Korea Forest Service 2014a). The widespread use of small-shovel in Korea can be attributed to the structure of private forest ownership (<2 ha of 75% of the total forest area), the low level of forest road density (3.1 m/ha), and the scarcity of knowledge of cable yarding (Korea Forest Service 2015). Further, the dilemmas associated with the operation of cable yarding machines are accepted to the high capital investment of the machinery with the wood value of markets since a forest owner only harvests wood once or twice in their life. For this

CONTACT Sang-Kyun Han hsk5311@korea.kr

reason, small-scale cable yarding systems have been suitable for stump-to-landing/forest road operations.

Although several studies have evaluated productivity and cost of small-scale cable yarding machines (Spinelli et al. 2010; Zimbalatti and Proto 2010; Proto et al. 2016), the Korea Forest Service (KFS) challenged and invited forestland managers, operators, and landowners to use cable yarding harvesting systems. Most forestland managers, operators, and small forest owners in Korea fear that cable yarding systems will result in a significant decrease in productivity and increase in costs. As a result, primary transportation with a cable yarder is rarely seen. Thus, this case study of small-scale cable yarding using a HAM300 aims to evaluate the productivity and costs of this technology in the Korean context.

In this study, we evaluate the economic feasibility of uphill and downhill cable yarding systems on tree-length (TL) harvesting method using a HAM300 cable yarder with a running skyline system. Specific research objectives of this study include: (1) comparing the productivity (m^3/PMH (Productivity Machine Hours)) and cost ($/PMH at machine utilization rate 75%) of different yarding directions; and (2) developing regression models through field-based experiments that can be used to test the spending time of one cycle of cable yarding operations.

2. Materials and methods

2.1 Study sites and harvesting system operations

This study took place on Japanese larch (*Larix leptolepis*) stands at Chunyang-myeon Bonghwa in the Gyeongsang-buk-do region of Korea (at latitudes 37°2′20–23″E and longitudes 128°50′25–37″N). The average diameter at breast height (DBH) of Japanese larch (*Larix leptolepis*) was 34 cm and average slope was 40.0% (Table 1). Small-scale cable yarding operations with a HAM300 were applied at two different clear-cutting sites (i.e. uphill and downhill yarding). These sites are described in Table 1 with information provided by the KFS (2014b). The two sites were close in proximity, stand age, and stand conditions, providing favorable conditions to compare uphill and downhill yarding.

The HAM300 cable yarding system was utilized to extract 10 m TL logs that were manually felled, delimbed, and processed at the stump using a chainsaw. Each site used either an uphill or downhill yarding method to haul logs to the forest road. In both areas, the yarding operation was done with a three-person crew: a yarder operator and two choker-setters with less than 5 years of experience. This meant that a yarder operator also had to be a landing chaser or a person responsible for removing the choker. The yarder was rigged in a running skyline system, which can be used to yard logs uphill or downhill in thinning operations and clear-cuts, or wherever there is a steep slope with decent deflection and a short yarding distance. It has a main line and haul-back lines that move the carriage in and out. Therefore, the carriage is controlled and pulled by the haul-back line during the downhill yarding operation.

Table 1. Description of study site characteristics.

	Uphill	Downhill
Area (ha)	1.0	1.2
Forest type	Japanese larch	Japanese larch
Stand density (m^2/ha)	325.0	325.0
Age class	V(40–50 year)	V(40–50 year)
Average DBH (cm)	34.0	34.0
Average height (m)	20.0	20.0
Average slope gradient (%)	40.0	42.0
Treatment	Clear-cut	Clear-cut

2.2 Description of machine specification

In the HAM300 tower yarder, a tower was mounted to a farm tractor with a three-point hitch for easy transportation on forest roads (Figure 2). The HAM300 was manufactured by the National Forestry Cooperatives Federation based on the Australian Koller K300T. The machine components and capabilities are: (1) the tractor must have a 59 kW (79 hp) engine supplying 48 kW to the PTO connection; (2) the cable capacity is 350 m × 16 mm for skyline, 350 m × 9.5 mm for mainline, and 500 m × 9 mm for haul-back line; (3) the slack-pulling carriage (HAM-C 1.0) can be remotely controlled; and (4) a three-person crew, including one machine operator and two choker-setters, is required (National Institute of Forest Science 2014).

2.3 Data collection and analysis

A time and motion study was conducted using a handheld stopwatch to collect cycle time data. The yarding cycle was

Figure 1. Primary transportation on steep slope in Korea. An excavator with a grapple throws cut-to-length logs (2–4 m in log length) downward to a forest road or skid trail below.


Figure 2. Small-scale cable yarder (HAM300) designed in South Korea. Uphill yarding (a), and downhill yarding (b).

divided into five distinct and commonly observed cycle elements: carriage out; lateral out; hook; lateral in; carriage in; and unhook (Conway 1976; Adebayo et al. 2007; Behjou et al. 2008; Proto et al. 2016). All delays were recorded and classified in one of three categories: operational; mechanical; and personal (Anderson et al. 2012). The following are the definitions of each cycle element:

- Carriage out: a cycle begins when the empty carriage is pulled out from the landing by gravity or the haul-back line on a steep slope to the hooking area.
- Lateral out: the lateral cable is dropped by the yarder operator and the cable is pulled by choker-setters.
- Hook: the choker-setters pull the lateral cable to drag the chokers over to the logs and set them.
- Lateral in: the yarding operator pulls the lateral cable with the mainline and carriage haul is dragged with the haul-back line.
- Carriage in: the haul is carried to the cable yarder with the haul-back line, and the yarder moves to the landing where the carriage comes in for unhooking.
- Unhook: the carriage arrives at the landing; the cycle ends when the carriage clears the landing to begin carriage out.
- Operational delay: removing and decking log at landing, and fighting the hang-ups.
- Mechanical delay: untangling between skyline and mainline, delay with dropping the skidding line, and breakdown.
- Personal delay: talking with yarding operator and choker-setters, and break time.

Productivity (m^3/hour), or volume yarded per hour, was determined using 300 pre-measured and marked logs (i.e. 150 at each site). Accurate small and large end diameter and length data were collected after the harvest operation. Logs were marked to associate cycle time with the volume of individual or groups of logs. Pre-marked log volumes (m^3) were calculated using Smalian's formula:

$$V = \frac{A_1^2 + A_2^2}{2} \times L \tag{1}$$

where V is the volume of the log in m^3, A_1 is the small end diameter of the log in m, A_2 is the large end diameter of the log in m, and L is the length of the log in m.

When the number was not clearly visible, an ocular estimation of log diameter was made.

Hourly machine costs ($/hour) for the HAM300 cable yarder were estimated using standard machine rate measurement practices (Brinker et al. 2002; Table 2). Cost factors and assumptions used for the calculation were collected from field observations and the National Institute of Forest Science (Table 2). Diesel prices were given as the local mean annual market prices for 2016 in Korea. Overhead, indirect, and profit allowance costs were excluded from the hourly machine costs.

Data collected were used to develop predictive equations with an ordinary least squares regression procedure in IBM SPSS Statistics for Windows v22.0 (IBM Corp., released 2013). The statistical stepwise selection procedure was used to select the best independent variables for developing a predictive productivity equation (Zayed and Halpin 2005). Independent variables such as small and large end diameter, length, yarding distance, lateral distance, and number of pieces per cycle were selected. The validation process was accomplished by comparing the outputs of developed models to actual site data. Therefore, 70% of collected data were used

Table 2. Summary of cost factors and assumptions used to calculate hourly costs.

Cost factors	HAM300
Purchase price (US$)	134,000[a]
Salvage value (% purchase price)	20
Economic life (years)	6
Interest (% average yearly investment)	10
Insurance (% average yearly investment)	3
Taxes (% average yearly investment)	2
Repair and maintenance (% depreciation)	80
Fuel consumption (liter/hour)	10.0[b]
Fuel cost ($/liter)	1.25
Lube and oil cost (% fuel cost)	40
Wages (US$/SMH)	15
Fringe benefits (% wage)	40
Scheduled machine hour (SMH/year)	2000
Utilization rate (%)	75
Machine cost ($/SMH)	60.83

Notes: [a]HAM300 price includes tractor price (US$48,000).
[b]Based on field observations.

for model building while 30% were used for validation (Zayed and Halpin 2005). A two-sample t-test ($\alpha = 0.05$) was used to determine the exact relation between the regression models and validation data. Finally, sensitivity analysis was performed to test the change in productivity of cable yarding in relation to change in yarding distance. Analysis was done to understand how sensitive the model is to small changes in the values of input variables (Hisel 2015).

Table 4. Description of the cycle element times (s) with percentage during the HAM300 yarding process.

	Uphill	Downhill
Carriage out	25 (11%)	35 (12%)
Lateral out	12 (5%)	7 (3%)
Hook	88 (39%)	90 (32%)
Lateral in	25 (11%)	37 (13%)
Carriage in	48 (21%)	61 (22%)
Unhook	29 (13%)	49 (18%)
Total	227	279

3. Results and discussion

3.1 Evaluation of uphill and downhill yarding productivity and cost

The average delay-free cycle time (DFCT) excluding set-up and disassembly times for downhill yarding was significantly longer than for uphill yarding (52 s/cycle, $P < 0.05$; Table 3), even though the average yarding distance and lateral yarding distance were slightly shorter in downhill yarding. Longer DFTC was mainly due to gravity, topography effects, and safety issues (MacDonald 1999; Proto et al. 2016). During the extraction, average payload size was 0.57 m^3/cycle and 0.61 m^3/cycle for uphill and downhill yarding, respectively, and there were no significant differences in mean DBH and payload size between study sites ($P > 0.05$). On the other hand, lateral distance for uphill yarding was considerably longer (40%) compared to the downhill yarding conditions, but there was no statistically significant difference ($P = 0.0785$). In downhill yarding, for example, the carriage moves up the haul-back line by the force of the drum with an interlocking mechanism on the yarder. A convex slope profile is not preferred for the installation of a yarder and extraction of logs due to visual limitation and little or no deflection. Therefore, cable yarding operations tend to be uneconomical on this slope profile (MacDonald 1999). In addition, controlling a log's descent is challenging as they tend to slide over stumps and begin rolling downhill in the landing area, which does not occur with uphill cable yarding (MacDonald 1999).

The cable yarder set-up and disassembly time for uphill and downhill yarding was observed to be 3 h 22 min and 5 h 15 min, respectively. Downhill yarding installation took almost half as much again set-up and disassembly time because this area presented a convex outline, which is not ideal for haywire and skyline installation (Spinelli et al. 2010). In contrast the uphill yarding site had a concave slope profile and this area provided much better conditions to rig the yarder (Kochenderfer and Wendel 1978; Spinelli et al. 2010). Thus, most operators prefer an uphill yarding system.

Table 3. Productivity and cost of HAM300 yarding operations.

	Uphill	Downhill
Average yarding distance (m)	55.0 (5–130)	53.0 (10–90)
Average lateral distance (m)	8.0 (0–40)	5.0 (0–25)
Average delay free cycle time[a] (s/cycle)	227	279
Average delay time (s/cycle)	99	193
Operational delay (%)	21 (48[b])	64 (8[b])
Mechanical delay (%)	68 (77[b])	20 (22[b])
Personal delay (%)	11 (4[b])	16 (3[b])
Log size (m^3/log)	0.57	0.61
Productivity (m^3/PMH)	9.04	7.87
Productivity (m^3/SMH)	6.29	4.65
Hourly cost (US$/SMH)		109.23[c]
Operation cost (US$/$m^3$)[d]	9.06	10.04

Notes: [a]Time excludes set-up and disassembly time at each site.
[b]Frequency.
[c]Hourly cost includes a three-person crew.
[d]Machine utilization rate = 75%.

During the study we noticed that most of the yarding time might be attributed to "carriage in" and "lateral in" processes. The time spent pulling the carriage was significantly longer in downhill yarding than uphill yarding ($P < 0.05$), although the average yarding distance and lateral distance were not significantly different ($P > 0.05$). The shorter yarding cycle time in the uphill yarding operation was mainly due to adequate clearance from the concave slope profile. Although all units were operated by the same person, the unhooking time for the downhill yarding area was significantly longer (20 s/cycle, $P < 0.05$) because of the chaser's safety problems (Conway 1982; Trzesniowski 1998).

In the yarding phase, the hooking time was the most time-intensive process of the total yarding cycle time. The time required to "hook" accounted for 37% and 32% of DFCT for uphill and downhill yarding, respectively (Table 4). Several studies have shown that hook procedures accounted for 30%–60% of DFCT (Conway 1982; Garland 2003; Hoffmann et al. 2015). Hartley and Han (2007), and Hoffmann et al. (2015) reported that the "hook" element was influenced by the cutting pattern, residual trees, and logs sizes, causing a human-controlled work pace. Furthermore, past studies reported that the choker-setter had a decisive role in determining the efficiency of the yarding performance (Garland 2003).

The overall productivity for uphill and downhill extraction with the HAM300 yarder was 9.03 m^3/PMH and 7.88 m^3/PMH at a cost of US$9.06 and US$10.04/m^3, respectively, even though the average yarding distance and lateral distance were slightly longer in uphill yarding. A higher productivity may have resulted if extraction to landings at the top of the slope raised productivity (Hartley and Han 2007). In addition, there were no significant differences between study sites ($P > 0.05$) in mean yarding distance ($P = 0.8184$), lateral distance ($P = 0.0785$), and payload size ($P = 0.0842$). The observed productivity was slightly lower compared with those presented in Cho et al. (2016), which observed that HAM300 uphill yarding produced 9.20 m^3/PMH with similar working conditions (average payload size at 0.62 m^3/cycle, slope at 30°, 47 m in yarding distances, 11 m in lateral distances). However, average DFCT (155 s/cycle) was 70 s shorter than this study. Productivity differences are mainly caused by operator and choker-setters using the same machine (Ovaskainen et al. 2004). Kärhä et al. (2004) reported that crew experience had up to 40% influence on harvesting machine productivity.

Compared to other small-cable yarding machines, the HAM300 may be an efficient in system productivity and cost within the variety of small-scale cable yarding operations previously studied (Spinelli et al. 2010; Zimbalatti and Proto 2010; Proto et al. 2016). These discussions may be argued as the site conditions, yarding distance, and machine configurations were not exactly the uniform for other studies. However, these results determined that this HAM300 can be a productive and cost effective option if you interested in yarding in small tract area.

Table 5. Productivity regression models.

Direction	Average delay free cycle time estimator (s)	R^2	P-value	N^a	Validation P-value[b]
Uphill	135.421 + 1.908 (yarding distance)	0.58	0.00	101	0.33
Downhill	128.158 + 1.408 (large end diameter) + 1.610 (yarding distance) + 3.057 (lateral distance)	0.54	0.00	56	0.49

Notes: [a]70% of the total observed data used for model development.
[b]P-value provided by two-sample t-test between predicted and observed data.

3.2 Delays

Delay times for the uphill and downhill yarding operations of the HAM300 are presented in Table 3. These times may depend on the yarding direction. The 94 s larger portion of delays recorded for downhill yarding was related to operational delays, such as dealing with hang-ups at stump, and removing and decking logs at landing. In addition, longer delays may depend on the slope profile (i.e. convex), since convex terrain obstruct yarder operator's field of view where was yarded downhill (Conway 1982; MacDonald 1999; Spinelli et al. 2010).

Observed personal delays (talking with yarding operator and choker-setters, and break time) for the uphill and downhill yarding were a small proportion (<16%) of total delay time. Kellog and Spong (2004) and Adebayo et al. (2007) found that personal delay generally constituted a small proportion of the total delay time, with operational delay comprising the highest proportion of the total delay time. During the downhill yarding operation, operational delays (removing and decking logs at landing, and dealing with hang-ups) represented the largest delay categories and had difficulty laterally yarding logs toward the yarding corridor and hauling logs (45%), followed by delays by loader piled operation at the landing (18%). Because this system was a visual limitation causing a convex slope profile and also had a runaway or slipped log damaged at landing area.

Behjou et al. (2008) found that mechanical delays (e.g. untangling between skyline and mainline, dropping the skidding line, and breakdown) occurred the most frequently and caused the longest delays. Frequent mechanical delays tend to be high during operations. However, the average mechanical delay times were higher than for other types of delays at uphill yarding unit since a start-up cable yarding operator used HAM300 for the first time. Untangling between skyline and mainline, and dropping the skidding line, constituted a greater percentage of uphill yarding operation than downhill causing an operator skill level.

Further, mechanical delays could be attributed to condition of machine (Adebayo et al. 2007) but this machine is almost brand new machine in 5 years. Thus, HAM300 might not be designed for professional cable yarding operations. For this reason, HAM300 machine improve its strength and durability to reduce the machine's repair time and re-evaluate the machine utilization .

3.3 Delay free cycle time regression models and sensitivity analysis between uphill and downhill yarding

The models developed for all the processes contain predictors that have significant P-values ($P < 0.05$) (Table 5). Model validation processes showed that the differences between the observed and predicted data were insignificant ($P > 0.05$) for the equations. This validation means that the productivity regression models are a good predictor for cycle times (Pan et al. 2008). These models did not include set-up, dismantling, or delay times.

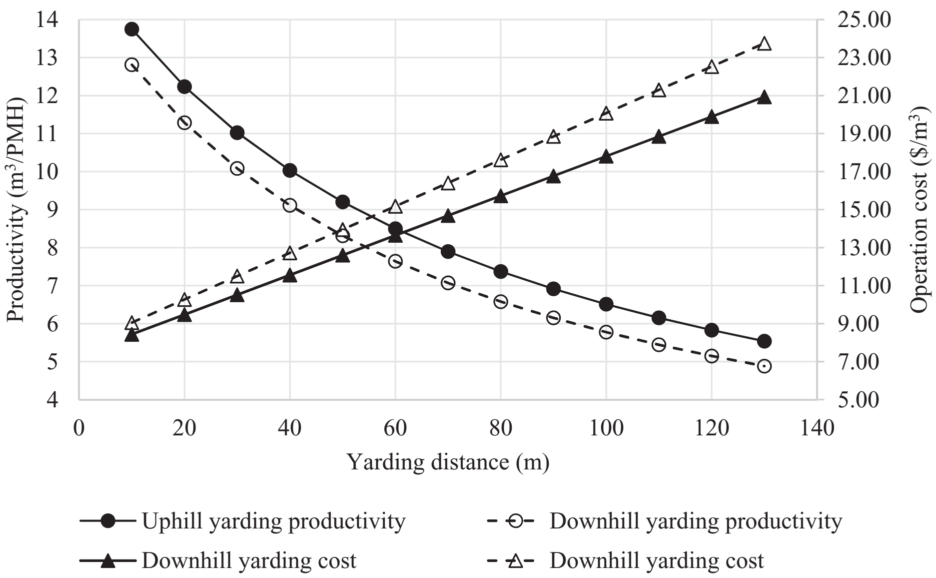

Figure 3. Effect of yarding distance on cable yarding productivity and operational cost.

The regression model for the HAM300 indicated that the DFCT was strongly influenced by yarding distance per yarding turn cycle time. These equations indicate that an increase in yarding distance could raise the DFCT, whereas species, diameter, height, lateral distance, and number of pieces had little effect on cycle time. Similar results were reported in Spinelli et al. (2010) and Proto et al. (2016). They found that yarding distance was the primary variable affecting yarding time consumption, as well as there being a positive relationship between extract consumption time and yarding distance.

Sensitivity analysis was performed to determine the primary effect of yarding distance on productivity. The HAM300 yarding productivity and DFCT were estimated assuming that other variables had a fixed average lateral distance of 7 m, 1.21 pieces per cycle, and large end diameter of 33 cm. Yarding distance was evaluated from 10 m and increased at 10 m intervals. The sensitivity test showed the overall productivity and DFCT for each additional yarding distance (Figure 3). The overall productivity of the cable yarding operation decreased with increasing yarding distance. The productivity of uphill yarding by distance was nearly 5% greater, with slightly lower costs than the downhill yarding operation. Capability production is used to more clearly describe the differences between yarding directions by HAM300 yarding operations. This follows the result that yarding is arranged for the rigging to be pulled uphill not downhill.

4. Conclusion

This field-based study was conducted to assess the economic feasibility of uphill and downhill yarding operations using a HAM300 yarder on clear-cut Japanese larch stands. In both stands, yarding productivity and cost were mainly affected by yarding direction. The average productivity of the different directions (uphill and downhill) when yarding processed logs from stump to roadside was 9.04 m^3/PMH and 7.87 m^3/PMH at a cost of US\$9.06/m^3 and US\$10.04/m^3 (75% machine utilization rate), respectively.

Yarding direction and slope profile had an influence on delay times since the yarding operator's field of view was obstcured. Operational delay times were greater when using downhill yarding compared to uphill yarding. In addition, mechanical delays were observed more often than operational and personal delays.

Yarding direction and distance were significant factors influencing productivity and cost. In sensitivity analysis, the uphill yarding had higher productivity and lower cost than downhill yarding. Furthermore, the productivity of the small-scale cable yarding operation increased when the yarding distance decreased. Based on these results, we recommend that the HAM300 yarder could be more productive for uphill yarding.

This study's findings show that the HAM300 may be a productivity- and cost-effective option for small-scale harvesting systems under similar site conditions and at less than a 100 m yarding distance. Further work is needed to compare productivity and costs under various site conditions.

Funding

This study was carried out with the support of R&D Program for Forest Science Technology (grant number 2013069B10-1719-AA01) provided by Korea Forest Service (Korea Forestry Promotion Institute).

References

Adebayo AB, Han H-S, Johnson L. 2007. Productivity and cost of cut-to-length and whole-tree harvesting in a mixed-conifer stand. For Prod J. 57(6):59–69.

Akay AE. 2005. Using farm tractors in small-scale forest harvesting operations. J Appl Sci Res. 1(2):196–199.

Anderson N, Chung W, Loeffler D, Jones JD. 2012. A productivity and cost comparison of two systems for producing biomass fuel from roadside forest treatment residues. For Prod J. 62(3):222–233.

Behjou F, Majnounian B, Namiranian M, DvoŘAk J. 2008. Time study and skidding capacity of the wheeled skidder Timberjack 450C in Caspian forests. J For Sci. 54:183–188.

Bjerkelund T. 1994. Design of forest operations methods for harvesting small crop trees selectively. Appl Ecol Action. 135–152.

Brinker R, Kinard J, Rummer B, Lanford B. 2002. Machine rates for selected forest harvesting machines. Circular 296 (revised). Auburn: Alabama Agricultural Experiment Station, Auburn University.

Cho M, Cho K, Jeong E, Lee J, Choi B, Han S-K, Cha D. 2016. Harvesting cost and productive of tree-length thinning in a *Pinus densiflora* stand using the tower yarder (HAM300). J For Environ Sci. 32 (2):189–195.

Conway S. 1982. Logging practices: principles of timber harvesting systems.ASan francisco, CA: A Forest Industries Book. Miller Freeman Publications.

Garland J. 2003. The basis for productivity improvement in cable harvesting from human resources. In Proceedings of the Workshop New Trends in Wood Harvesting with Cable Systems for Sustainable Forest Management in the Mountains. Austria

Ghaffariyan MR, Brown M. 2013. Selecting the efficient harvesting method using multiple-criteria analysis: a case study in south-west Western Australia. J For Sci. 59(12):479–486.

Harrison S, Herbohn J, Niskanen A. 2002. Non-industrial, smallholder, small-scale and family forestry: what's in a name ?. Small-scale For Econ, Manage Policy. 1(1):1–11.

Hartley DS, Han H-S. 2007. Effects of alternative silvicultural treatments on cable harvesting productivity and cost in Western Washington. Western J Appl Forestry. 22(3):204–212.

Hiesl P, Benjamin JG. 2013. Applicability of international harvesting equipment productivity studies in Maine, USA: a literature review. Forests. 4(4):898–921.

Hisel P. 2015. Forest harvesting productivity and cost in Maine: new tools and processes. Doctoral Dissertation, Orono, ME: University of Maine.

Hoffmann S, Jaeger D, Schoenherr S, Talbot B. 2015. Challenges in mechanization effects of small diameter eucalyptus harvesting operations with a low capacity running skyline yarder in Southern China. Forests. 6:2959–2981.

IBM Corp. Released. 2013. IBM SPSS statistics for Windows, version 22.0. Armonk (NY): IBM Corp.

Jourgholami, M. 2012. Small-scale timber harvesting: mule logging in Hyrcanian forest. Small-scale Forestry. 11(2):255–262.

Jourgholami, M. 2014. Productivity and cost of a small-scale timber forwarding system using farm tractors in the Hyrcanian forest, Northern Iran. Taiwan J For Sci. 29(2):103–116.

Kellogg LD, Bettinger P, Robe S, Steffert A. 1992. Mechanized harvesting: compendium of mechanized harvesting research. Corvallis (OR): Forest Research Laboratory, Oregon State University.

Kellogg LD, Spong B. 2004. Production and costs of cut-to-length thinning: experience from the Willamette young stand project. Corvallis (OR): Forest Research Laboratory, Oregon State University.

Kochenderfer JN, Wendel GW 1978. Skyline harvesting in Appalachia. Forest Service Research Paper NE-400 1–9.

Korea Forest Service . 2014a. Monitoring and improvement of the actual use condition for activating the use of forest machinery.

Korea Forest Service . 2014b. Timber Harvesting Project Planning, Yeongju National Forest Station.

Korea Forest Service . 2015. Statistical yearbook of forestry.

Kärhä K, Rökkö E, Gumse S-I. 2004. Productivity and cutting costs of thinning harvesters. Int J Eng Sci. 15.43–56.

MacDonald AJ, . 1999. Harvesting systems and equipment in British Columbia., Forest Engineering Research Institute of Canada. 197.

Marenče J, Krč J. 2016. Possibilities of using small tractors for forestry operations on private property. Croatian J For Eng. 37(1): 151–162.

National Institute of Forest Science 2014. Cable yarding operations manual, pp. 122.
Ovaskainen H, Uusitalo J, Väätäinen K. 2004. Characteristics and significance of a harvester operators' working technique in thinnings. Int J Eng Sci. 15:67–77.
Pan F, Han H-S, Johnson LR, Elliot WJ. 2008. Production and cost of harvesting, processing, and transporting small-diameter trees for energy. For Prod J. 58(5): 47–53.
Park J-H, Kim K-M, Eom C-D, Jung D-J. 2013. A study on log diameter classes of Korean softwood log. J Korean Wood Sci Tech. 41(4):337–345.
Parker R, Bowers S. 2006. Timber harvesting options for woodland owners, Corvallis, OR: The Woodland Workbook, Oregon State University EC1582
Proto AR, Skoupy A, Macri G, Zimbalatti G. 2016. Time consumption and productivity of a medium size mobile tower yarder in downhill and uphill configurations: a case study in Czech Republic. J Agr Eng. XLVII(551):216–221.
Russell F, , Mortimer D. 2005. A review of small-scale harvesting systems in use worldwide and their potential application in Irish forestry, Dublin, Ireland: National Council for Forest Research and Development. p. 48.
Sennblad G. 1995. A farm tractor as a base machine. Small Scale Forestry U Agr Sci, Sweden. 2(9)5:8–12.
Seo YO, Lumbres RIC, Jung SC, Won HK, Lee YJ. 2015. Application of national forest inventory data to estimate management ratios for private forests in Chungnam province. J Agirc Life Sci. 49(4): 31–37.
Spinelli R, Magagnotti N, Lombardini C. 2010. Performance, capability and costs of small-scale cable yarding technology. Small-scale Forestry. 9:123–135.
Stanczykiewicz A, Szewczyk G, Kulak D. 2015. Damage to advance growth resulting from timber harvesting during final cuttings. Balt For. 21:144–151.
Trzesniowski A. 1998. Wood transport in steep terrain. Proceedings of the seminar on environmentally sound forest roads and wood transport, 17–22 June 1996, Sinnaia. Romania: FAO Rome. 405–424.
Updegraff K, , Blinn CR. 2000. Applications of small-scale forest harvesting equipment in the United States and Canada, Minneapolis, ME: University of Minnesota. p. 51.
Visser R, Stampfer K. 1998. Cable extraction of harvester felled thinnings: an Austrian case study. J Forest Eng. 9(1):39–46.
Wilhoit J, Rummer B. 1999. Application of small-scale systems: evaluation of alternatives. An ASAE Meeting presentation. Toronto, Ontario Canada Paper no. 99-5056
Yu A, Gallagher T, Mitchell D, O'Neal B. 2016. Application of a small-scale equipment system for biomass harvesting. Small-scale Forestry. 16(1):133–146.
Yun JI. 2009. A simple method using a topography correction coefficient for estimating daily distribution of solar irradiance in complex terrain. Korean J Agr Forest Meteorol. 11(1):13–18.
Zayed TM, Halpin DW. 2005. Productivity and cost regression models for pile construction. J Constr Eng Manage. 131(7):779–789.
Zimbalatti G, Proto AR. 2010. Timber extraction with a cable crane in south Italy. FORMEC, Forest Engineering Meeting the Needs of the Society and the Environment. Padova, Italy.