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# Harvesting Cost and Productive of Tree-Length Thinning in a *Pinus densiflora* Stand Using the Tower Yarder (HAM300)

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## Abstract

Logging equipment and method have a major influence on harvesting productivity and cost. This study investigated the productivity and operational costs of tree-length cable yarding system using HAM300, a domestically developed tower yarder. We tested HAM300 for thinning operation in *Pinus densiflora* stands at Gangreung, Gangwon-do on April, 2014. To assess the productivity we conducted time study for each stage of the operation. When the average time/cycle was examined for each stage of the operation, the longest was for yarding (241 sec), followed by delimbing (237 sec), felling (153 sec), and processing (103 sec). Furthermore, productivity for felling was 8.6 $m^3$/hr, followed by delimbing (5.1 $m^3$/hr), yarding (3.5 $m^3$/hr), and processing (8.1 $m^3$/hr). The total cost for the tree-length logging system was 58,446 won/$m^3$, of which the majority was incurred by the yarding cost at 46,217 won/$m^3$ (79.3%), whereas the lowest cost was for felling at 2,359 won/$m^3$ (4.1%). We suggest that it is necessary to foster specialized operators and provide training in operating the tower yarder thereby implementing efficient harvesting system resulting from low-cost yarding.

**Key Words:** cable logging, harvesting cost, tower yarder, tree-length logging

## Introduction

The forest area in South Korea as of 2014 was about 6,400,000 ha, which accounts for 63.9% of the total land area and total tree growing stock per ha was 142.2 $m^3$ (KFS 2015). Since forest age-class structure has unbalanced with 65% of the total forest area consisting of aged forests of age-class IV or higher, it is necessary to conduct intensively harvest-based silviculture practices such as thinning and clearcut. Recently, the Korea Forest Service (KFS) has increased timber self-sufficiency from 16.7% in 2014 to 21% in 2017 (KFS 2015).

A decrease in the human population living in rural and mountain areas, and the increased age of traditional forestry workers has led to difficulties securing forest labor and a consequent need for the mechanization of forestry work. However, the current harvesting system primarily consists of cut-to-length logging using a wood grab bucket attached to an excavator. Such indiscriminate operations including logging road construction during harvesting cause severe disturbances to forest soils resulting in reduction of site productivity. Hence, it needs to introduce a system using a

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cabled, high-performance tower yarder for whole-tree or tree-length logging that is suited to the country's mountainous terrain and can minimize damage to forest soils (Cho et al. 2015).

Several studies have examined the cable logging operations in South Korea. Woo et al. (1990) analyzed the costs for manual yarding and yarding by using a small, mobile cable crane (K-300). Han et al. (2008) examined the difference in productivity between upward and downward cable yarding system in a *Larix leptolepis* forest using a tractor-mounted yarder (Chuncheon Tower Yarder). In terms of studies on whole-tree logging systems, Lee et al. (2013) analyzed the cost and productivity using a swing yarder, whereas Cho et al. (2014) examined the cost and productivity from felling using a chainsaw to yarding using the tower yarder (Koller K301-4). For tree-length logging systems, Han et al. (2014) studied the cost and productivity of different machines, including a tractor-mounted yarder (Chuncheon Tower Yarder), tower yarder (RME-300T), and tractor winch (FARMI), whereas Cho et al. (2015) analyzed the operational costs and productivity of a tower yarder (Koller K301-4). Thus, there has been many researches on the RME-300T, Koller K-300, 301, Chuncheon Tower Yarder, and swing yarders, but there is still little information regarding the cost and productivity of the tower yarder (HAM300) developed domestically in 2014.

The objective of this study was to provide supporting data for implementation of efficient timber harvesting systems in the country's forestry settings. To this end, we examined harvesting costs and productivity of tree-length logging system using the HAM300 in a *P. densiflora* thinning area located in Gangneung, Gangwon.

## Materials and Methods

### Tree-length logging system

After felling the trees with chainsaws and delimbing as part of the tree-length logging process, HAM300 was used for upward cable yarding to adjacent forest road. Then, the whole tree stems were cut on a forest road using chainsaws (Fig. 1).

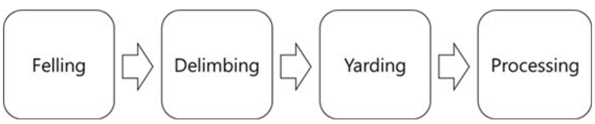


**Fig. 1.** Schematic of the harvesting system.

The chainsaw (ZENOAH5201, Husqvarna Zenoah Co., Ltd) used for felling, delimbing, and cutting had 49.3 cc displacement, 4.9 kg weight, an 18 inch guide bar, and 0.53 L fuel tank capacity. The yarding operation utilized the HAM300, developed domestically, with a maximum yarding distance of 300 m, a speed of 150-250 m/min, and a wireless remote control-operated conveyor (170 kg in weight).

### Study site

Forest thinning was conducted in a *P. densiflora* plantation area ($37^{o}$ 42' 8.25" N, $128^{o}$ 46' 38.37" E) located in Gangreung, Gangwon. Total logging area was 3.4 ha, average slope gradient was 30°, average tree height was 14 m (max 21 m, min 8 m), and average diameter at breast height was 34 cm (max. 58 cm, min. 22 cm).

### Methods

The time and motion study was applied to separate each stage of the harvesting operation into its constituent processes (Han et al. 2008; Lee 2013). Constituent processes in the felling stage were the time it took to move to the trees for felling, time to clear the surrounding area, time to fell the trees, and delay times, such as time for machine maintenance and fueling. Constituent processes in delimbing included movement time to the trees for felling, time to delimb the felled trees, and delays time. Yarding was performed in teams of four, with one person operating the tower yarder and three chokermen. The constituent processes were sending trees to the conveyer, horizontal pull, choke installation, lateral yarding, yarding, choke disassembly, rope elevation, and delays time. Constituent processes in log processing were movement time, cutting, and delays.

### Analysis

The operational costs (won/$m^3$) for each work process were calculated using the machine costs (won/hr) and the productivity ($m^3$/hr), according to the following formula:

$$\frac{\text{Machine cost (won/hr)}}{\text{Productivity (m}^3\text{/hr)}} = \text{Harvesting cost (won/m}^3\text{)}$$

**Productivity**

Productivity ($m^3$/hr) was calculated from the number of logs produced per hour (logs/hr) and the volume per log ($m^3$/log). Specifically, the number of logs produced per hour was obtained using continual working time measured for each constituent process, and the log volume was calculated using Smalian's formula (Sajdak et al. 2014).

Scheduled machine hours (SMH) refers to the time to complete a day's work from start to finish. Productive machine hours (PMH) was obtained by subtracting the delays time from the SMH (i.e. PMH=SMH-Delays).

**Delays**

Delays were divided into mechanical delays and non-mechanical delays. Mechanical delays were those caused by breakage or repair of the equipment. Non-mechanical delays were divided into operational delays and personal delays, where operational delays were those that occurred during work, whereas personal delays referred to time for workers to rest or relieve physiological needs (Vitorelo et al. 2011; Anderson et al. 2012).

Machine utilization was an important factor in analyzing the productivity and costs, and it was calculated as follows:

$$\text{Utilization (\%)} = \frac{\text{PMH}}{\text{SMH}} \times 100$$

**Machine costs**

Machine costs were divided into fixed costs, operating costs, and labor costs. Fixed costs were those incurred irrespective of machine operation, including depreciation, interest, insurance, and tax. Operating costs were those incurred when the machine was working, including fuel and lubricant costs. Machine costs were calculated using a machine rate calculation that takes into account annual machine usage time (Miyata 1980; Han et al. 2014; Cho et al. 2015).

Depreciation: Depreciation assumed that the value of equipment decreased at a constant rate for each year of its economic life. The mathematical formula is

$$D = \frac{(P-S)}{N}$$

Where D is depreciation cost, P is the initial investment cost of equipment, S is the salvage value, and N is the economic life in years (Miyata 1980; Han et al. 2014; Cho et al. 2015).

Interest, insurance, and tax: Interest, insurance, and tax include the interest on funds that were spent to acquire the equipment. Because this amount must be considered as an opportunity cost when it was invested in other purposes, the average yearly investment (AYI) needed to be calculated (Miyata 1980; Han et al. 2014; Cho et al. 2015).

$$AYI = \frac{(P-S)\times(N+1)}{2N} + S$$

Accordingly, the annual interest could be calculated as AYI×interest rate (%), the insurance cost could be calculated as AYI×insurance rate (%), and tax could be calculated as AYI×tax rate (%) (Miyata 1980; Han et al. 2014; Cho et al. 2015).

Repair and maintenance costs: Repair and maintenance (R&M) costs were calculated using the repair and maintenance coefficient r and the depreciation cost (Miyata 1980; Han et al. 2014; Cho et al. 2015).

$$R\&M = D \times r$$

Fuel costs: Fuel costs were analyzed based on the average fuel price for the 2nd week of August 2014 (Korea National Oil Corporation 2014).

Labor costs: Labor costs were the costs for special labor, standard labor, and logging categories defined in the "Government Standards for Unit Labor Costs in the 2nd Half of 2014" (Construction Association of Korea 2014).

## Results and Discussion

### *Factors for calculating machine costs*

The machine cost factors for calculating operational costs at each stage of the operation were deduced from a survey based on previous research methods (Miyata 1980), and are summarized in Table 1. Overseas, the factors for

**Table 1.** Cost factors and assumptions used for machine rate calculations

| Cost factor | Unit | Harvesting system | | | | |
|---|---|---|---|---|---|---|
| | | Felling (chain saw) | Delimbing (chain saw) | Yarding (HAM 300) | Processing | |
| | | | | | (Chain saw) | (Wood grap) |
| Purchase price | won | 900,000 | 900,000 | 92,000,000 | 900,000 | 54,000,000 |
| Economic lives | years | 1 | 1 | 7 | 1 | 5 |
| Salvage value | % | 0 | 0 | 10 | 0 | 30 |
| Scheduled operating time | hr/year | 1,500 | 1,500 | 300 | 1,500 | 2,000 |
| Annual interest rate | % | 15 | 15 | 15 | 15 | 15 |
| Repair and maintenance | % | 120 | 120 | 100 | 120 | 80 |
| Oil price | won/L | 1,747 | 1,747 | 1,556 | 1,747 | 1340 |
| Coefficient of lubricant | % | 59 | 62 | 37 | 68 | 40 |
| Fuel consumption | L/hr | 1 | 1 | 7 | 1 | 6 |
| Daily wage of operator | won/day | 122,125 | 122,125 | 106,569 | 122,125 | 106,569 |
| Daily wage of ground crew | won/day | - | - | 86,686 | - | - |

**Table 2.** Predicted delay-free average cycle time and production rate

| | Cycle time (sec) | Prod. rate | |
|---|---|---|---|
| | | ($m^3$/PMH[a]) | ($m^3$/SMH[b]) |
| Felling | 153 | 14.5 | 8.6 |
| Delimbing | 237 | 7.6 | 5.1 |
| Yarding | 241 | 9.2 | 5.4 |
| Processing | 103 | 19.2 | 8.1 |

[a]Productive machine hour.
[b]Scheduled machine hour.

different types of mechanical equipment has prepared through many relevant research cases (Brinker et al. 2002), but these data are still not sufficient for forestry setting in Korea, and as such further research will be required to increase the accuracy of these factors.

### *Production rates*

The average time for each stage of the operation was yarding (241 sec), delimbing (237 sec), felling (153 sec), and cutting (103 sec)(Table 2). Yarding had longest working time because of its complexity and the broad scope of the work. Meanwhile, delimbing took a long time because of obstacles to the workers movement and delimbing of felled trees scattered in the forest floor. Productivity for felling was 8.6 $m^3$/SMH, which was higher than the productivity of 4.83 $m^3$/SMH measured by Han et al. (2009) for a *P. koraiensis* thinning stand with slope gradient (24°), mean log volume (0.29 $m^3$), felling time excluding delimbing (217 sec) with a rate of 16.6 logs/hr. In spite of the log volume of 0.6 $m^3$ produced in the present study, there was no substantial difference in the number of logs felled per hour, suggesting that the average volume per log had a major influence on felling productivity.

Productivity for delimbing was 5.1 $m^3$/SMH, which was lower than the productivity of 6.09 $m^3$/SMH measured by Cho et al. (2015) for a *L. leptolepis* thinning stand with slope gradient (18°), mean log volume (0.32 $m^3$), and an SMH of 187 sec/log. Although the mean log volume (0.5 $m^3$) was higher in the present study, the slope gradient in the *L. leptolepis* stand was lower at 19° (Cho et al. 2015), and the differences in species branch characteristics and delimbing volume per hour apparently had a major factor on delimbing productivity.

Yarding productivity was 9.2 $m^3$/PMH, which was lower than that in a previous study by using a Chuncheon yarder in a *L. leptolepis* thinning stand resulting in the productivity (11.8 $m^3$/PMH) for tree-length, upward cable logging (Han et al. 2008). The working conditions for yarding in Han et al. (2008) were average slope gradient (30°), average lateral yarding distance (11 m), average yarding distance (47 m), and average carrying capacity (0.51 $m^3$/cycle), which were similar to the present study. However, the mean PMH was 155 sec, which was lower than the 241 sec obtained in the present study. It appeared that the low productivity for yarding was caused by inexperience operators and a lack of specialized operators with the present tower yarder HAM300 because it has recently been introduced into Korea.

Processing productivity was 8.1 $m^3$/SMH, which was approximately 2.5-fold higher than the productivity of 3.3 $m^3$/SMH in a previous study (Han et al. 2008) using a wood grab bucket and chainsaws for tree-length logging of *L. leptolepis* with mean PMH (303 sec), and mean log volume (0.35 $m^3$). Despite the average log volume being higher in this study than that of Han et al. (2008), the higher productivity occurred because the cutting process took less time.

### *Delays*

The delay time and ratio for each process are shown in Table 3. Among felling delays, operational delays accounted for 76.2%, of which sharpening was the longest at 50.3%, followed by 12.1% for oiling, 9.1% for brushing, and 4.7% for the remaining (e.g., bar and tree hang-ups). Personal delays accounted for 20.1%, which equated to worker rest time. Among delimbing delays, operational delays accounted for 62.9%, of which waiting was the longest at 23.6%, followed by 18.0% for sharpening, 13.8% for oiling, and 7.5% for others (e.g., bar and tree hang-ups). Personal delays accounted for 37.1%, which was worker rest time. Among yarding delays, operational delays accounted for 76.3%, of which corridor changes was the longest at 40.7%, followed by 17.3% for waiting, 15.8% for hang-ups in residual trees, and 2.4% for a re-chocking. Mechanical delays accounted for 17.7%, which was a repair time, and personal delays accounted for 6.0%, which was a worker rest time. Among cutting delays, operational delays accounted for 94.9%, of

**Table 3.** Summary of delays for total operation

| | Operational delay (sec) | Personal delay (sec) | Mechanical delay (sec) | Total delay (sec) | Total production time (sec) | Utillzation rate (percent) |
|---|---|---|---|---|---|---|
| Felling | 80 (76.2)[a] | 21 (20.1) | 4 (3.7) | 105 (100) | 258 | 59.3 |
| Delimbing | 71 (62.9) | 42 (37.1) | 0 (0.0) | 113 (100) | 350 | 67.7 |
| Yarding | 126 (76.3) | 10 (6.0) | 29 (17.7) | 165 (100) | 407 | 59.4 |
| Processing | 134 (94.9) | 4 (2.4) | 3 (2.7) | 141 (100) | 244 | 42.2 |

[a]Value in () indicates % of total.

**Table 4.** Felling cost in this study

| | | Felling (chain saw) | Delimbing (chain saw) | Yarding (HAM 300) | Processing (Chain saw) | Processing (Wood grap) |
|---|---|---|---|---|---|---|
| Machine utilization (%) | | 59 | 68 | 59 | 42 | |
| Fixed costs (won/hr) | Depreciation | 600 | 600 | 39,429 | 600 | 4,380 |
| | Interest, insurance and tax | 90 | 90 | 28,257 | 90 | 3,006 |
| Operating costs (won/hr) | Fuel | 414 | 425 | 2,888 | 295 | 1,340 |
| | Lube | 138 | 142 | 963 | 98 | 536 |
| | Repair and maintenance | 1,214 | 1,064 | 66,378 | 1,706 | 4,467 |
| Labor costs (won/hr) | Labor | 15,266 | 15,266 | 45,828 | 15,266 | 13,531 |
| | Benefit | 1,664 | 1,664 | 4,995 | 1,664 | 1,475 |
| | Insurance | 1,620 | 1,620 | 4,864 | 1,620 | 1,436 |
| Total machine costs (won/hr) | | 20,287 | 20,344 | 165,089 | 20,126 | 26,953 |
| Hourly productivity ($m^3$/hr) | | 8.6 | 5.13 | 3.8 | 8.1 | |
| Production costs (won/$m^3$) | | 2,359 | 3,966 | 46,217 | 5,672 | |
| Percent of total (%) | | 4.1 | 6.9 | 79.3 | 9.8 | |
| Total cost (won/$m^3$) | | | | 58,446 | | |

which waiting was the longest at 61.0%, followed by 21.5% for sharpening, and 12.4% for others (e.g., bar hang-ups, slash disposal, and oiling). Mechanical delays accounted for 2.7%, which was repair time, and personal delays accounted for 2.4%, which was worker rest time.

### Production costs

The total costs for the tree-length logging system were 58,446 won/$m^3$. Yarding had highest costs at 46,217 won/$m^3$ (79.3%), followed by 5,672 won/$m^3$ (9.8%) for cutting, 3,966 won/$m^3$ (6.9%) for delimbing, and 2,359 won/$m^3$ (4.1%) for felling (Table 4). Similarly, Kim et al. (2011) found that the harvesting cost from felling to processing was 45,007 won/$m^3$ of which yarding had highest cost at 26,073 won/$m^3$ (57.9%). Also, Cho et al. (2014) found that yarding cost 14,557 won/$m^3$ (60.4%) had highest among total harvesting costs (24,086 won/$m^3$). As shown in many studies, yarding costs account for the largest proportion of operational costs for harvesting. If special operators are trained and educated in use of the domestic tower yarder HAM300 which has recently been introduced to the operators in Korea, it could be possible to implement efficient harvesting system resulting from low-cost yarding.

## Conclusion

This study examined the productivity and operational costs of tree-length cable yarding using a domestically developed tower yarder HAM300 in a *P. densiflora* thinning stand.

Felling had highest productivity (8.6 $m^3$/hr), followed by delimbing (5.1 $m^3$/hr), yarding (3.5 $m^3$/hr), and processing (8.1 $m^3$/hr). The total cost for the tree-length logging system was 58,446 won/$m^3$, of which the majority was incurred by the yarding cost at 46,217 won/$m^3$ (79.3%), whereas the lowest cost was for felling at 2,359 won/$m^3$ (4.1%).

Felling and delimbing processes using chainsaw exhibit differences in productivity and operational costs according to the log volume and the species branch characteristics. Yarding using the tower yarder HAM300 had lower productivity than the RME-300T or Koller K301-4. This occurred because delays, which have a major influence on yarding productivity, constituted a large proportion of the total working time at 40.6%, and operational delays in particular, including installation, disassembly, and waiting accounted for 76.3% of the total delay time. Therefore, it is thought that inexperience operating the tower yarder HAM300, which has recently been introduced into Korea resulting in the low productivity, and that there is a need to foster specialized operators and provide training in operating the tower yarder.

## References


Adebayo AB, Han HS, Johnson L. 2007. Productivity and cost of cut-to-length and whole-tree harvesting in a mixed-conifer stand. For Pro J 57: 59-69.

Anderson N, Chung WD, Loeffler D, Jones JG. 2012. A productivity and cost comparison of two systems for producing biomass fuel from roadside forest treatment residues. For Pro J 62: 222-233.

Brinker RW, Kinard J, Rummer B and Lanford B. 2002. Machine rates for selected forest harvesting machines. Circular 296 (Revised). Alabama Agricultural Experimental Station, Auburn, Alabama, USA. pp 32.

Cho KH, Cho MJ, Han HS, Han SK, Cha DS. 2015. Harvesting cost of tree-length thinning in a larix leptolepis stand. J Korean For Soc 104: 221-229.

Cho MJ, Cho KH, Oh JH, Han HS, Cha DS. 2014. Harvesting productivity and cost of whole-tree clear cutting using a tower yarder in a Larix leptolepis Stand. J For Sci 29: 107-112.

Construction association of Korea. 2014. Government Standards for Unit Labor Costs in the 2nd Half of 2014. pp. 9-10.

Enforcement Decree of the Act on the Collection, etc., of Premiums for Employment Insurance and Industrial Accident Compensation Insurance. Article 12, Clause 4. 2013.

Han WS, Cho KH, Oh JH, Song TY, Kim JW, Shin MY. 2009. Felling productivity in korean pine stands by using chain saw. J Korean For Soc 98: 451-547.

Han WS, Han HS, Kim NH, Cha DS, Cho KH, Min DH, Kwon KC. 2014. Comparison of harvesting productivity and cost of cable yarding system. J Korean For Soc 103: 87-97.

Han WS, Han HS, Kim YS, Shin MY. 2008. The yarding productivity and cost of cable yarding operation by yarder attached on tractor -using the Chuncheon tower-yarder-. J Korean For Soc 97: 641-649.

Kim MK, Kim JH, Kwon HJ, Park SJ. 2011. An analysis on the productivity and cost of logging operation in whole-tree logging operation system. In: Proceedings of the Annual Meeting of Korean Forest Society, Gyeongju, Korea, pp. 760-763. (in Korean)

Kim MK, Park SJ. 2012. An analysis of the operational time and productivity in whole-tree and cut-to-length logging operation system. J Korean For Soc 101: 344-355.

Kim MK. 2010. An analysis on the productivity and cost of logging operation in whole-tree logging operation system. MS thesis. Kyungpook National University, Daegu, Korea. (in Korean)

Korea Forest Service. 2015. Statistical Yearbook of Forestry, pp 31-41.

Korea National Oil Corporation. 2014. Oil Price Database. http://www.knoc.co.kr. Accessed 8 Feb 2016.

Lee JA. 2013. Productivity and cost analysis of whole-tree harvesting system using swing-yarder. MS thesis. Kangwon National University, Chuncheon, Korea. (in Korean)

Miyata ES. 1980. Determining fixed and operating costs of logging equipment. U.S. Department of Agriculture Forest Service Gen. Tech. Re. NC=55. pp. 16.

Sajdak M, Velázquez-Martí B., López-Cortés I., Fernández-Sarría A., Estornell J. 2014. Prediction models for estimating pruned biomass obtained from Platanus hispanica Münchh. used for material surveys in urban forests. Ren Ene 66: 178-184.

Vitorelo B, Han HS, Elliot W. 2011. Productivity and cost of intergrated harvesting for fuel reduction thinning in mixed-conifer forest. For Pro J 61: 664-674.

Woo BM, Park JM, Lee JW, Chung NH. 1990. A study on economical analysis of yarding operation by cable crane. J Korean For Soc 79: 413-418.