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Factors Affecting Lumber Conversion Rate of Sawmill Industry in South Korea

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Abstract : This study is conducted to investigate the factors affecting lumber conversion rate of sawmill industry in South Korea. Data were obtained from the survey of 38 sawmills in all geographic regions of South Korea. The variables examined in this study were region, softwood/hardwood log, domestic/imported/both log, the number of power-driven carriages (PDC) installed, the year when and country where PDCs was manufactured, the horse power of PDC, the number of labors required to operate each PDC, the sawing capacity of mill (mill size), and the types of major product and by-products. The lumber recovery factor (LRF) of sawmills were significantly influenced by the origin of logs, level of PDC automation, sawmill size, and size of logs (measured in diameter and length) while not by the location of the mill, types of major product and by-product, log species, and characteristics of PDC. Although these results provide useful information for understanding the technological characteristics of the Korean sawmill industry, further investigation with larger sample is necessary to reveal the more reliable characteristics of sawmill industry in South Korea.

Keywords **:** *lumber recovery factor, technological characteristics, Korean sawmill industry*

Introduction

Sawmill industry has played an important role in wood product industries of South Korea over the past few decades. For the last three decades, lumber production has been steadily increased. For instance, the lumber production was about 1.1 million cubic meter in 1970 and increased to 4.8 million cubic meter in 2002 (KFRI 2002). On the other hand, the number of sawmills slightly decreased (Figure 1). With the increases of log price and transportation costs, the price competitiveness of lumbering declined (KFRI 2005). As a result, only those of large scale and of specialty products can maintain their lumber production, and consequently, the number of sawmill in Korea had drastically decreased to about 700 compared to nearly 2,000 in the early 1970s (KFRI 2005). Figure 2 shows the distribution of sawmills in each province, Jeollabuk-do, Gyungki-do, Gangwon-do, Jeollanam-do, and Kyeonsang-do, of South Korea (KFRI, 2005).

Wade *et al.* (1992) used the conversion efficiency of raw material to lumber to determine the technological level of sawmill industry. The conversion efficiency has become increasingly important with increasing the price of logs and decreasing the volume of standing timbers. Subsequently, the technological improvement of wood products industries has steadily increased the conversion efficiency (Wade *et al.* 1992). There has, however, been no study about the conversion efficiency of sawmills in South Korea. The conversion efficiency of sawmills can be represented by lumber recovery factor (LRF). The LRF is widely used to determine the technological level of wood product industries in many countries (Steele *et al.* 1991).

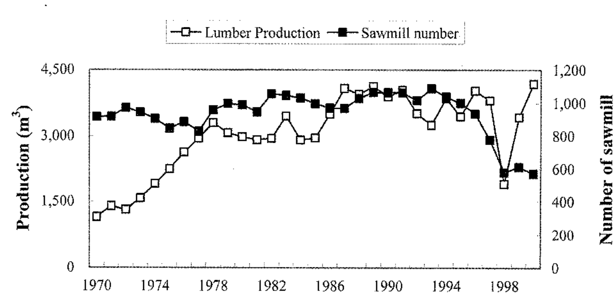

Figure 1. Lumber production and number of sawmills in South Korea, 1970 to 2000.

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The LRF of a sawmill may be influenced by many variables. The relationship between LRF and the variables associated with the technological level of sawmills, such as characteristics of sawing machines and logs, annual production, region, and mill size, was investigated by some researchers in the past. Log characteristics, such as log diameter and length, have been shown to influence LRF (Steele and Wagner 1990; Steele *et al.* 1986; Wade *et al.* 1992). For example, LRF is improved with the increase of log diameter because a lower percentage of log volume is lost during the sawing process. It is also well known that the longer the log length, the lower the LRF, because of the increased influence of log taper (Steele and Wagner 1990).

Several studies were investigated the effects of the kerf width of headrig and resaw on the conversion efficiency of a sawmill (Hallock 1964; Steele and Wagner 1990; Steele *et al.* 1986; Steele *et al.* 1991). In these studies, LRF significantly increased as the kerf width was reduced. Consequently, a negative relationship is expected between the width of kerf and LRF. Currently, the reduction of kerf width plays an important role to increase the conversion efficiency of a sawmill. In this study, the characteristics of a power-driven carriage (PDC) were included as variables because PDC is the most important machine in lumbering, and all sawmills surveyed in this study possessed more than one PDC. Prior to 1990, automated PDCs could hardly be found in Korea where the operators' skill was an important factor for log positioning and sawing patterns. From the early of 1990s, sawmills have gradually installed a milling system with computers and advanced scanning machines, and skilled labors as a technician and engineer were hired to deal efficiently with the automated systems.

The scale of sawmill production per annum (scale of mill) has an influence on LRF (Steele and Risbrudt 1985). In these studies, sawmills with a higher productive capacity input more resources to efficient machining and/or quality control efforts. In addition, large-size sawmills could invest more capital for installing new machines with thinner saw-blades and lower sawing variation. Therefore, large-size sawmills could increase efficiency in manufacturing and controlling the qualities of products. But there would be limits to the economy of scale (Steele *et al.* 1986).

This study was conducted to quantify the relationship between LRF and variables affecting lumber conversion rate of sawmill industry in South Korea. The purpose of the study is to reveal the technological characteristics of sawmill industry in South Korea with the focus of the influence of sawmill specifications and log characteristics on conversion efficiency.

Methodology

Although many variables influence LRF of sawmills, the characteristics of log and sawing machine, region and sawmill size were included in this study. Data were obtained from the survey of 38 sawmills. The sawmills were selected randomly from 719 sawmills operated currently in South Korea, and were distributed nationally. To investigate the regional differences of LRF, this survey was conducted in five regions. The five regions were identified as Region A (Gyungki-do), Region B (Kyeongsang-do), Region C (Jeollanam-do), Region D (Jeollabuk-do and Chungcheong-do), and Region E (Gangwon-do). Each region has a representative harbor, which was unloaded logs imported from abroad, of South Korea (Figure 2). Table 1 shows the distribution of sawmills by region and annual lumber production.

Log types, such as domestic or imported log, hardwood or softwood, were included for analyzing the effect of log characteristics on LRF. The average diameter and length of the log sawmilled were also included as variables. In order to obtain the relationship between LRF and the characteristics of sawing machine, the specifications of PDC, such as the year when the PDC was manufactured, the country where the PDC was manufactured, and the horse power of PDC, were contained in the questionnaires of this study. Additionally, the number of labors required to operate each PDC were counted to

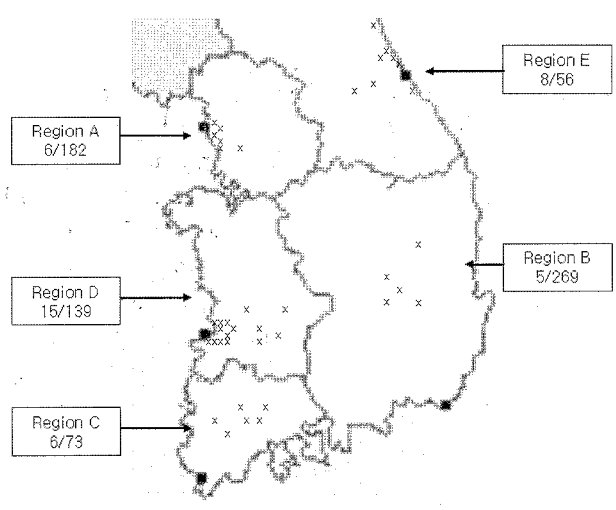

Figure 2. Regional location of sawmills used in this study; the numbers in box (sawmills surveyed in this study/total sawmills located in the region); A: Gyungki-do, B: Kyeonsang-do, C: Jeollanam-do, D: Jeollabuk-do and Chungcheong-do, and E: Gangwon-do; and ■ means a representative harbor, which unloaded logs imported from abroad, in each region; x means a sawmills surveyed in this study.

Table 1. Distribution of sawmills surveyed by region and annual lumber production.

Region*	Harbor	Annual lumber production (× 1,000m³)					
		Total	~1	1.1~5	5.1~10	10.1~15	15.1~
A	Incheon	5	1	2	1	1	
B	Pusan	5	1	1	1	1	1
C	Mokpo	6		3	3		
D	Gunsan	14	1	2		3	8
E	Donghea	8	3	4	1		
Total		38	6	12	6	5	9

*A: Gyungki-do; B: Kyeonsang-do; C: Jeollanam-do; D: Jeollabuk-do and Chungcheong-do; and E: Gangwon-do.

Table 2. Average regional values of LRF and variables (log type, power-driven carriage, sawmill size and products types).

Variables		Total	Region [1]				
			A	B	C	D	E
LRF [2]		62.32	59.38	63.00	62.83	62.00	65.83
Log type	Sw/Hw [3]	32/6	8/0	1/4	5/0	12/2	6/0
	Do/Im/Both [4]	5/25/8	3/3/2	0/4/1	0/2/3	2/11/1	0/5/1
	ALL [5]	7.00	10.12	7.55	6.81	4.42	7.32
	ALD [6]	33.66	27.38	37.50	49.80	26.86	35.00
PDC	Possession Number	1.42	1.25	1.00	2.20	1.36	1.50
	Year [7]	1996	1997	1995	1993	1997	1996
	Country Do/Im [8]	32/6	7/1	4/1	4/1	11/3	6/0
	Horse power	51.83	45.25	63.00	70.00	46.61	37.50
	Automation [9]	2.18	2.50	2.00	2.40	1.71	2.67
Sawmill size		8,907	6,683	8,920	17,340	889,857	6,950
Products Type	Major prod. S/B/T [10]	28/2/8	4/0/4	3/2/0	4/0/1	14/0/0	3/0/3
	By-prod. Sl/Ch/Sd [11]	23/6/9	6/0/2	3/2/0	1/2/2	9/2/3	4/0/2

[1]A: Gyungki-do and Incheon, B: Kyeonsang-do, C: Jeollanam-do, D: Jeollabuk-do and Chungcheong-do, and E: Gangwon-do; [2]LRF: Lumber recovery factor; [3]Sw/Hw: Softwood/hardwood; [4]Do/Im/Both: Domestic log/imported log/domestic and imported log; [5]ALL: Average log length; [6]ALD: Average log diameter; [7] Year when the PDC was manufactured; [8]Country where the PDC was manufactured (Do/Im: Korean/Japan); [9]The number of labor required to operate each PDC; [10]S/B/T: Scant/board/timber; [11]Sl/Ch/Sd: Slab/chip/sawdust.

determine the automation level of PDC. Annual sawmill production (APRD) was also included as one of variables in this study.

The effects of type of major products and by-products on LRF were also investigated. In general, the major products of sawmills in Korea are largely divided into scant, board and timber, which is classified by the size of each product. The thickness of scant, board and timber are less than 2 inch, 2~5 inch, and more than 5 inch, respectively. The type of by-products, such as slab, chip and sawdust, can also affect the LRF of sawmills in Korea. From this survey, it was recognized that sawmiller has been controlled the production of by-products depending on the price of each by-product. Therefore, the type of by-products was included in this study as a variable.

This study was designed to investigate the effects of variables on LRF. At first, the general linear model (GLM) procedure was performed to characterize the linear relationship between LRF and continuous variables, such as APRD, the horse power of the PDC, the year when the PDC was manufactured, log length and diameter. Effects of explanatory variables, such as region, log type, log origin, the country where the PDC was manufactured, the number of labors required to operate each PDC, and the types of major product and by-product, on LRF were examined by the analysis of variance (ANOVA). Significant effects with a $p < 0.05$ were further characterized by the Duncan's multiple range test. This test was conducted to identify the statistical differences of LRFs in the variables, such as log type, log origin, log diameter, log length, countries the PDC was manufactured, horse power of PDC, the number of labor required to operate each PDC, sawmill size, types of major products and by-products (Table 3). A 95% confidence level was used in all statistical tests.

Table 3. Summary of statistical analyses for the effects of each variable on the LRF of sawmill in South Korea.

Variable		Sample No.	LRF[1)]	
			Range	Mean[2)]
Log type	Softwood	32	40 to 80	61.66 A
	Hardwood	6	55 to 80	65.83 A
Log origin	Domestic	5	40 to 60	50.80 B
	Imported	25	45 to 80	63.68 A
	Both	8	57 to 75	65.25 A
Average log diameter	less than 25 cm	8	40 to 70	54.88 B
	26~50 cm	27	50 to 80	64.22 AB
	more than 51 cm	3	60 to 70	65.00 A
Average log length	less than 5 m	18	40 to 65	58.11 B
	6~10 m	12	57 to 80	66.83 A
	more than 11 m	8	50 to 80	65.00 A
Country where the PDC was manufactured [3)]	Domestic	32	40 to 80	62.28 A
	Imported	6	45 to 80	62.50 A
Horse power of PDC [3)]	less than 25 HP	9	50 to 80	64.56 A
	26~50 HP	19	40 to 80	63.16 A
	more than 51 HP	10	45 to 65	58.70 A
Automation level of PDC [3)]	1 labor	14	45 to 65	60.14 AB
	2 labors	4	50 to 65	58.50 B
	3 labors	20	40 to 80	65.00 A
Sawmill size	less than 2,000 m^3	15	40 to 80	60.07 B
	2,000~8,000 m^3	12	55 to 80	66.25 A
	more than 8,000 m^3	11	45 to 80	60.17 B
Major product	Scant	28	55 to 80	64.83 A
	Board	2	45 to 70	58.00 A
	Timber	8	40 to 80	58.89 A
By-product	Slab	23	40 to 80	62.91 A
	Chip	6	45 to 80	65.71 A
	Sawdust	9	40 to 80	62.36 A

[1)]LRF: Lumber recovery factor; [2)]Means within a column followed by a same letter are not significantly different at p=0.05 (Duncan's multiple range test); [3)]PDC: power-driven carriage.

Results and discussion

Table 2 gives the average regional values for LRF and all variables. The average LRF value of Region E (Gangwon-do) was the highest, followed by Region B (Kyeonsang-do), Region C (Jeollanam-do), and Region D (Jeollabuk-do). Region A (Gyungki-do) was the lowest among the regions investigated in this study. However, there were no significant differences between LRFs of each region (p=0.24). In addition, there was no significant difference between the LRFs of sawmills, which are manufactured products from softwood and hardwood (Table 3). When region and log type were included as variables in the early stage of this study, the differences of the LRFs were expected. The contrary results, however, might be due to the lack of number of sawmills surveyed in this study (sample=38). No difference of the LRFs by log type is probably thought that the number of the sawmills dealt with hardwood (6 sawmills) comparing with that of softwood (32 sawmills) is insufficient.

Meanwhile, the LRF of sawmills was influenced by the origin of logs, such as domestic and imported logs. Currently, most sawmills in South Korea are producing lumbers from imported logs. In this study, the number of sawmills using domestic, imported, and both logs to produce lumbers were 5, 25, and 8. As shown in Table 3, the LRF of sawmills using domestic logs was significantly lower than LRFs of sawmills using imported and both types logs (p=0.01), but there was no significant difference between LRFs of sawmills using imported and both types logs (p=0.30). These results might be due to the differences of log characteristics between domestic and imported logs. For example, the average diameters of domestic and imported logs surveyed in this study were 21.20 cm and 36.48 cm. As explained in the result of Wade *et al.* (1992), with the increase of log diameter, less amount of wood was lost as a percentage of log volume due to slabbing and edging, and thus the LRF of sawmills using domestic logs might be lower than those of sawmills using imported and both types logs.

Regardless of log types, LRF did not increase linearly with an increase of log diameter (p=0.30), but was influenced by log diameter (Table 3). For instance, LRF of logs with less than 25 cm was significantly lower than LRF of logs with more than 50 cm (p=0.03). However, there were no significant difference between LRFs of logs with 26~50 cm and more than 51 cm (p=0.41), and less than 25 cm and more than 51 cm diameters (p=0.09). These results demonstrated that the LRF difference of domestic and imported logs was originated from the difference of log diameter. In the relationship of LRF and log length, LRF was not linearly increased with increasing a log length (p=0.10). As shown in Table 3, the LRFs of logs with 6~10m (p=0.01) and more than 11m lengths (p=0.04) were significantly higher than that of logs with less than 5m length, but there was no significant difference between LRFs of logs with 6~10m and more than 11m lengths (p=0.47). These results were in conflict with those of other studies. Howard (1988) explained that there was a negative relationship between log length and LRF because longer logs have greater amounts of wood lost as slabs due to its taper. In Korea, the lengths of logs used for the production of lumber are 1.8m, 2.7m, 3.6m and 4.8m. Logs with 3.6m and 4.8m length are mainly used for the production of timbers, such as a post, pole and beam, but logs with shorter lengths for the manufacture of scants. Therefore, longer logs are required less sawing processes than shorter logs, and thus might be higher LRF than shorter logs.

The effects of power-driven carriage (PDC) characteristics, such as the year and country the PDC was manufactured, horse power, and automation level, on LRF were examined. The sawmills surveyed in this study possessed 1.42 PDC per one sawmill on average. Regionally, as shown in Table 2, the possession rate of Jeollanam-do was the highest, and that of Kyeonsang-do was the lowest. No linear relationship between LRF and year when the PDC was manufactured was detected (p=0.92). When LRFs were compared by the production country of PDC, LRF was not influenced by the country where the PDC was manufactured (p=0.48). Most sawmills in South Korea have used domestic and imported PDCs for producing lumbers. In this study, 32 sawmills are using a domestic PDC, and 6 sawmills are using an imported PDC. The imported PDCs were produced in Japan. The horse power of PDC included in this study was ranged from 20HP to 150HP, and the number of sawmills with less than 25HP, 26~50HP, and more than 51HP PDCs were 9, 19, and 10, respectively. In addition, the horse power of PDCs used in Jeollanam-do was the highest and one in Gangwon-do was the lowest (Table 2). LRF was not linearly increased with increasing the horse power of PDCs (p=0.29). When compared with LRFs by the horse power of PDC (Table 3), the LRF was not significantly affected by the horse power of PDC (p=0.31). To identify the relationship between LRF and the automation level of PDC, the automation level was included in one of variables. In this study, the automation level of PDC was defined by the number of labors involved in the operation of each PDC. In all sawmills surveyed in this study, PDC was operated by one to three labors. The LRFs of sawmills, which PDC was operated by one, two and three labors, were 60.14%, 58.50% and 65.00%, respectively. The significant difference of LRF by the number of labors involved in the operation of each PDC was found just between one and three labors (Table 3). In Korea, most large-scale sawmills possess PDCs operated by one labor, and the sawmills are producing lumbers on a large scale. Whereas most small-scale sawmills are producing small amount of lumbers by PDCs operated by two or three labors. Therefore, small-scale sawmills pay more attention to the quality of lumber and LRF than the quantity of lumber produced from their sawmills. Consequently, the LRF of sawmills, which are operated a PDC by more than two labors, might be higher than that of sawmills having a PDC operated by one labor. Regionally, the sawmills, located in Jeollabuk-do, involved the fewest labor (1.70 labors), and ones in Gangwon-do involved the most labor (2.67 labors) for operating each PDC.

The annual sawmill production (APRD) investigated in this study was 8,907m^3 on average. The APRD of sawmills in Jeollabuk-do was the highest and one in Gangwon-do was the lowest (Table 2). The regional order of regional APRD was as follows; Jeollabuk-do and Chungcheong-do (889,857m^3), Jeollanam-do (17,340m^3), Kyeonsang-do (8,920m^3), Gangwon-do (6,950m^3), and Gyungki-do and Incheon (6,683m^3). APRD was not increased proportionally with increasing the LRF of sawmills (p=0.24). Steele *et al.* (1991) pointed out that moderately large sawmills may be much efficient in manufacturing and quality control of their products, and thus the LRF of the sawmills is higher than that of small sawmills. To compare their result with our result, sawmills were classified into small (~2,000m^3), medium (2,001~8,000m^3) and large (8,001m^3~) by APRD. As shown in Table 3, the LRF of medium-size sawmills was statistically higher than those of small- and large-size sawmills (p=0.03), but there was no significantly difference between LRFs of small- and large-size sawmills (p=0.49). These results are probably due to the difficult management of large-size sawmills for producing lumbers. Steele *et al.* (1991) also shows a similar result that very large sawmills are less efficient converters of sawing logs than are moderately large sawmills.

The sawmills surveyed in this study are mainly manufacturing scants, boards and timbers. For instance, scants was produced by 28 sawmills. Only two sawmills have been produced boards, and the major product of reminding sawmills was timbers (Table 2). In addition to the major products, pallets and specially ordered products were produced by a couple of sawmills. In our study, LRF not influenced by the type of major products in sawmills (p=0.13). These results might be obtained due to lack of the numbers of sawmills, and especially the number of sawmills produced boards. Except for types of major products, LRF is also affected by size of each major product. However, the effect of size of major products on LRF was not included in the result of our study because most sawmills investigated were manufactured similar products. Therefore, further study is required to investigate clearly the effects of major product type and size on LRF. As shown in Table 2, regionally, half of sawmills in Gangwon-do and Gyungki-do are mainly producing timbers. The timbers produced by sawmills of the regions were used for constructing temples and traditional houses, whereas most of sawmills in Kyeonsang-do, Jeollanam-do, Jeollabuk-do and Chungcheong-do were produced scants and boards for the construction of general houses. Among 38 sawmills surveyed, 23 sawmills obtained slabs, 9 sawmills sawdusts, and 6 sawmills chips as a by-product. Table 3 shows the comparison of sawmills' LRFs by the type of by-product. Similar to the relation between LRF and major product type, there were no significant differences among the types of by-products (p=0.65). These results show that by-products are just derivatively produced in the process of lumber production, and consequently the types of by-products might have not affected in the LRF of sawmills.

Conclusion

Although the sample size of this study was not big enough to prove the statistical significance in the relationship between LRF and variables affecting lumber conversion rate of sawmill industry in South Korea, the results indicated that some of variables, such as log origin, log length and diameter, sawmill size, and the automation level of PDC, could influence LRF. Based on the results, it is expected that the LRF of sawmills in South Korea would be higher when they utilize imported logs of larger diameter with log length of 6~10m, equip with a PDC operated by more than two labors, and produce 2,000~8,000m^3 lumber annually. In particular, it was found that log characteristics, which influenced the LRF of sawmills, were closely related to log origin.

The results of this study also indicated that sawmills of medium-size up to 8,000 cubic meters per annum in production capacity are more efficient than sawmills of small and large size in converting logs to lumber. A further investigation is necessary for what derives the variations in LRF of Korean sawmills over time and their implications to the international competitiveness.

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