Analyzing the Antecedents and Consequences of Manual Log Bucking in Mechanized Wood Harvesting

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ABSTRACT. The study focused on the frequency of applying a manual tree-stem bucking to logs in coniferous forests of Finland. The aim of the study was to clarify harvesting conditions where manual log bucking is utilized most and the effects of the utilization of manual bucking on the log bucking outcome. In addition to the stm Big Data of harvesters, in order to investigate the consequences of manual log bucking, data from the enterprise resource production (ERP) systems of wood procurement organization and sawmills was collected, as well as harvester operators were interviewed. The study results illustrated that the share of manual bucking of Norway spruce (*Picea abies* L. Karst.) logs was, on average, 46% and with Scots pine (*Pinus sylvestris* L.) logs 67%. The operators used manual bucking more frequently in thinning stands with small-sized and defected log stems. When the utilization degree of manual log bucking was high, the utilization of log sections with spruce and pine log stems was lower, logs were shorter and the volume of logs was smaller. Furthermore, log percentage and apportionment degree were significantly lower when the shares of manual log bucking were higher. The relative production value of spruce logs was lower, and correspondingly the relative production value of pine logs was higher when applying plenty of manual bucking. On the basis of the study results, it can be recommended that nowadays the target for the manual log bucking percentage with spruce must be less than 20–30% of the total log volume cut. In the future, our aim must be fully automatic or semi-automatic and harvester computer-aided bucking based on the quality grades of the log section zones of log stems with pine and spruce. It will require equipping harvesters with novel mobile laser scanning (MLS) and machine vision (MV) applications.

Introduction. Globally the wood harvesting is becoming increasingly mechanized both in tree-length (TL) and cut-to-length (CTL) systems. The main drivers for this trend are the potential for increased productivity and reduced costs, the labour-related issues (i.e. enhancing safety, labour shortages and rising wage costs), and the increased global competition in forest industries [1]. Almost 100% of wood harvesting is currently carried out using mechanical harvesting systems in Finland [2]. In the 2010's around 1,870–1,990 harvesters and 1,930–2,020 forwarders have annually been used in wood harvesting operations in Finland [3].

The wood harvesting is a crucial element in supply chains of forest industries. There will be a time when a forest owner realizes a return from the investments of decades. As the whole volume of a tree is seldom merchantable and the prices for the different sections of a tree stem vary a lot, the most important issue is cross-cutting (i.e. bucking) the tree stem into sawlogs, veneer logs and pulpwood poles for the mills of forest industries [4]. According to the classical study of the value recovery by Geerts and Twaddle [5], even 40% of the total monetary value of stems can be lost during wood harvesting operation, and the biggest single source of loss comes from log bucking in which up to more than 20% of the potential value can be lost.

The CTL method is used for the wood procurement of industrial roundwood in Finland, and also in many other countries in the world. In customer-driven wood procurement process of CTL method, tree stems are bucked into favourable log dimensions at the harvesting site. In this process, the sawmill customers will have information about the demand of the markets of sawn goods, and thus order the target distribution of logs based on the demand of end-product markets. In the forest, harvester computer calculates the optimal bucking proposals for each tree stem by taking into account the bucking instructions of harvesting site. The bucking instructions consist of target distribution, price matrix and the various other bucking parameters and guidelines. The goodness of bucking outcome can be evaluated with several attributes, for instance using the dimensions, value and reject percentage of logs and apportionment degree [e.g. 6–11].

The modern harvesters are equipped with powerful on-board computers, advanced measurement and monitoring technologies, geographical information systems and communication systems, as well as optimization models designed to assist the harvester operator in the log bucking decision-making process of the CTL system. These applications of modern harvesters have a significant potential to increase efficiency and value gain from the whole supply chain of the forest industries [1].

When cutting Norway spruce (*Picea abies* L. Karst.) log stands, the guideline for the harvester operator is to utilize the bucking proposals by the harvester computer (i.e. automatic bucking) as much as possible because there is a belief that, hence, the bucking outcome of log stems can be maximized at the harvesting site [12, 13]. Of course, the harvester operator can utilize manual bucking (i.e. the operator him-/herself decides the cross-cutting points of log, or in other words, no bucking with the suggestions supplied by the harvester's automatic system) with damaged or defected parts of log stems – for instance butt rot, crookedness, top changing, vertical branch, large branch – or some other reasons in the stand.

The quality of Norway spruce does not fluctuate much and the values of different lumber grades are quite small. Correspondingly, the values of Scots pine (*Pinus sylvestris* L.) lumber are significantly dependent on the quality of pine log [12]. The log sections of Scots pine stem are generally regarded as dividing into three quality zones: 1) a knotless or slightly knotty butt zone, 2) the dead knot zone in the middle of the stem, and 3) the fresh knot zone on the upper part of the log section in the stem. Consequently, when cross-cutting pine log stems, the quality bucking is conducted and the bucking is not necessarily managed by according to the target and price matrices. Hence, it is a target that the harvester operator will utilize a lot of manual bucking on the log section of pine.

Several research groups [6–8, 11, 14–18] have compared the bucking options (i.e. manual vs. automatic bucking) and underlined that the gains of automatic or computer-aided bucking are bigger than manual bucking. However, almost all these studies [6–8, 14–18] have been carried out in the context of manually cross-cutting, i.e. there has been automatic, optimal computer-based bucking and manually bucking by a lumberjack with a chain saw in the comparison. That is to say, no mechanized cross-cutting with modern harvesters in these log bucking studies.

During the last seven years (2010–2016) in Finland, the annual cuttings of softwood logs have been, on average, 23.3 million solid m^3 over the bark (later only: m^3) of which the proportion of Norway spruce log cuttings has been 53% and the share of Scots pine log cuttings 43%. Furthermore, the average log consumption of sawmilling industry has been annually 23.9 million m^3 in the 2010's in Finland [19]. Nevertheless, how much softwood logs mechanically harvested are bucked manually and automatically? For successful implementation of mechanical wood harvesting, this information is mandatory. However, it is not yet known in Finland.

Therefore, Stora Enso Wood Supply Finland (WSF), the University of Eastern Finland, Metsäteho Ltd. and Ponsse Plc. undertook a study on the frequency of applying a manual tree-stem bucking to logs in coniferous forests of Finland. The aims of the study were to clarify:

- Harvesting conditions where manual log bucking is utilized most;
- The main reasons for using plenty of manual bucking;

• The effects of the utilization of manual bucking on the log bucking outcome (Fig. 1).

The hypotheses of the study were:

• With Norway spruce log stems, the best bucking outcome is achieved when manual bucking is minimized;

• In cuttings of Scots pine log stands, the best bucking result is reached when manual bucking is maximized.

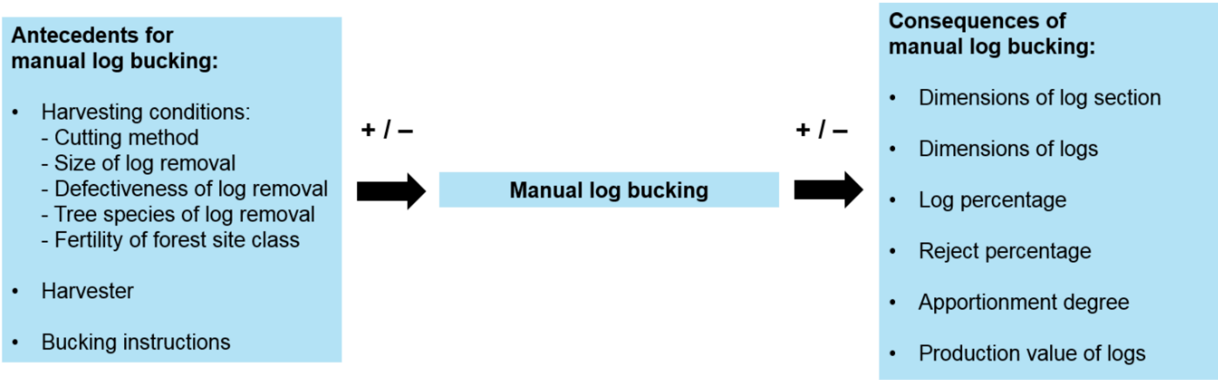

Fig. 1. The framework of the study on manual log bucking.

Material and methods. For the study, the stm files [20] of 55 harvesters were collected in June and August 2015 from the harvesters of eastern Finland and in December 2015 and January 2016 from the harvesters operating in southern Finland at the harvesting sites of Stora Enso WSF. The starting point of stm data collection was the beginning of 2014. All harvesters of the study were Ponsse (Beaver, Ergo 6w, Ergo 8w, Fox, HS16 Ergo and Scorpion) harvesters (Fig. 2).

Fig. 2. Log bucking in the study with the Ponsse Beaver harvester in a spruce-pine-mixed stand. Photo: Jyri Änäkkälä..

There were 1–2 operators in each study harvester. When analyzing the stm data and calculating the volumes of manual bucking on the log section of stems, the manual bucking volumes were considered the following cross-cuttings:

• Logs with bucking carried out manually by the operator;

• Offcut pieces (length of <1.5 m) by sounding log section;

• Pulpwood poles cut from the log section of stem.

All other buckings on the log section of stems were classified automatic bucking in the study. The manual log bucking percentage was determined by dividing manually bucked log volume by the total log volume. The percentage of the defected timber of log stem was defined by dividing the volume of manually bucked offcuts and pulpwood poles on the log section of stem by the total volume of log section.

The spruce and pine log lengths used were mainly 3.7–5.5 m with the increments of 0.3 m. Also, some shorter (3.1 & 3.4 m) and longer (5.8 & 6.1 m) log lengths were applied. The minimum top diameter of spruce logs was 16 cm and 15 cm with pine logs in the study. The total stm data of softwood log stems was 1,296,297 m^3 and 1,964,884 log stems. The softwood log removal was more than 20 m^3 on each harvesting site. There were totally 5,634 harvesting sites in the study. The stm material varied from 1,848 to 52,897 m^3/harvester.

In addition to the stm data of harvesters, in order to detect the consequences of manual log bucking, data from the enterprise resource production (ERP) systems of Stora Enso WSF and sawmills was collected. Total data from the ERP system of Stora Enso WSF was 91,496 m^3 and from the ERP systems of sawmills 74,803 m^3.

The goodness of bucking outcome was evaluated with the following attributes:

• The utilization of log section (volume, length, top diameter of log section);

• Log percentage;

• Log dimensions (volume, length, top diameter of logs);

• Reject percentage;

• Apportionment degree;

• The relative production value of logs.

Of the attributes of the consequences of manual log bucking, the reject percentage, apportionment degree, and the relative production value of logs were investigated at the batch level of harvesting sites (i.e. the combination of 1…n harvesting sites). The rest of the attributes (i.e. the utilization of log section, log percentage, and log dimensions) were the harvesting site-specific variables based on the stm data of harvesters in the study.

Moreover, all harvester operators who worked during 2015 in the harvesters studied (N=81) were aimed at to be interviewed for the study. Total of 74 harvester operators were interviewed by phone by two research scientists in December 2015 – January 2016. Thus, the response rate of interview survey was 91%. When the operators were interviewed, they were asked to estimate how much they had bucked Norway spruce and Scots pine logs with manual bucking of their total log volumes cut during the period of December 2014 – November 2015. In the interview survey, the following questions were also asked:

• Which bucking option (i.e. automatic or manual bucking) produces better bucking result in the opinion of an operator;

• Which elements does the good bucking outcome consist of;

• What are the effects of harvesting conditions and the other variables on the utilization degree of manual bucking on the log section of spruce and pine log stems;

• What are the most common reasons for the utilization of manual bucking with spruce and pine log stems;

• Is the operator willing to take part in bucking education session if the education will be organized.

The variables related to manual log bucking in the study were analyzed using distributions, mean values, standard deviations and Spearman's rank correlations (ρ). The differences between the classified groups of the manual bucking percentages of spruce and pine logs were researched by the Mann-Whitney test (U) and the Kruskal-Wallis one-way ANOVA test (χ^2) because the circumstances (i.e. ratio or interval scales in variables and/or normal distribution of samples) for using parametric tests did not exist.

Results. Totally 4,051,804 softwood logs of which 2,496,356 spruce logs and 1,555,448 pine logs were bucked in the study. The results illustrated that the manual bucking percentage of spruce logs was, on average, 45.5% and with pine logs 67.4%. There was statistically significant positive correlation ($\rho=0.579$; $p<0.001$) between the shares of manual bucking of spruce and pine logs: when the manual bucking percentage with spruce was low, also the manual bucking percentage of pine logs was low at the harvesting site in question, and vice versa (Fig. 3).

Fig. 3 presents also that there was a huge variation of the shares of manual bucking on harvesting sites of the study. Moreover, there was a significant correlation ($\rho=0.708$; $p<0.001$) between the shares of manual bucking in cross-cutting spruce and pine logs by harvester (Fig. 4). There were statistically significant differences between study harvesters in the manual log bucking percentages with spruce (χ^2=2,107; $p<0.001$) and pine (χ^2=1,773; $p<0.001$).

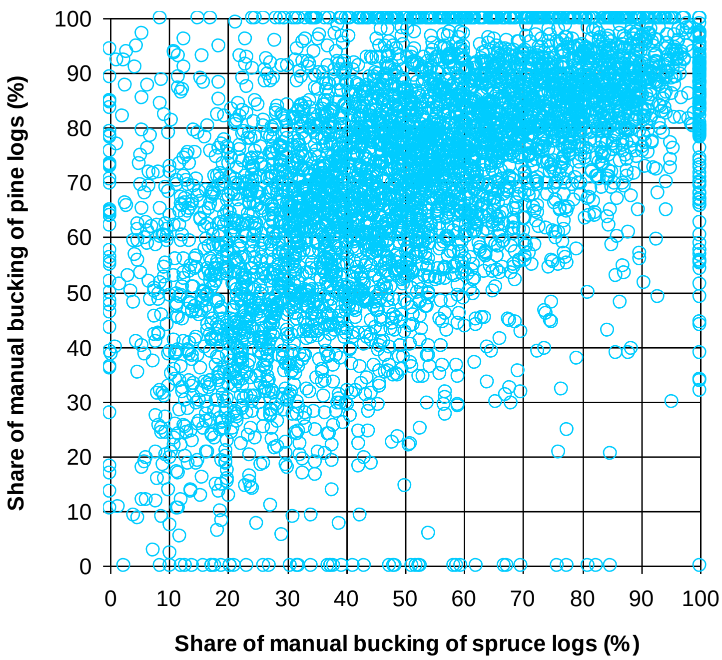

Fig. 3. The shares of manual bucking of Norway spruce and Scots pine logs by harvesting site (n=4,964) in the study.

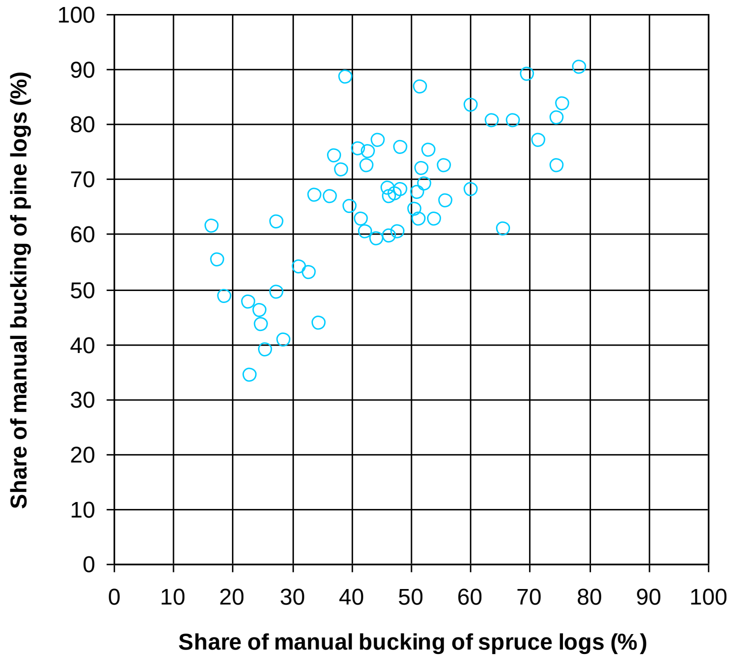

Fig. 4. The average shares of manual bucking of Norway spruce and Scots pine logs by harvester (n=55).

The results demonstrated that the operators apply manual bucking with both spruce and pine log stems more frequently in thinning stands with small-sized and defected log stems (Tables 1 and 2, Figs 5 and 6). Respectively, some manual bucking was used when bucking log stems from regeneration fellings with large-diameter and good-quality log stems. On the contrary, forest site class had no significant effect on the utilization of manual bucking in the study (Tables 1 and 2, Figs 5 and 6).

Table 1. Harvesting conditions and classified groups related to the shares of manual log bucking with Norway spruce logs.

	Share of manual log bucking (%)			Statistically significant differences between Groups A, B & C
	<30 [A]	30–60 [B]	>60 [C]	
Cutting method (%)				A-C***, B-C***
Regeneration felling	75.8	70.4	56.0	
Thinning	14.7	21.1	36.2	
Other cutting	9.5	8.5	7.8	
Height of removal of spruce log stems (m)	18.4	18.1	17.2	A-B***, A-C***, B-C***
DBH of removal of spruce log stems (cm)	27.6	27.5	26.5	A-B**, A-C***, B-C***
Volume of removal of spruce log stems (dm^3)	712	694	607	A-B***, A-C***, B-C***
Share of defected timber on spruce log section (%)	11.9	13.3	14.8	A-B***, A-C***, B-C***
Share of spruce of log stem removal (%)	62.0	62.1	54.2	A-B**, A-C***, B-C***
Share of pine of log stem removal (%)	32.4	31.0	36.2	A-B**, B-C***
Share of hardwood of log stem removal (%)	5.6	6.9	9.6	A-B**, A-C***, B-C***
Forest site class (%)				
Upland forest with grass-herb vegetation	26.6	28.1	29.1	
Moist upland forest site	71.8	69.2	65.0	
Dry upland forest site	1.5	2.7	5.9	

DBH = Diameter at breast height ($d_{1.3}$); * p<0.05; ** p<0.01; *** p<0.001.

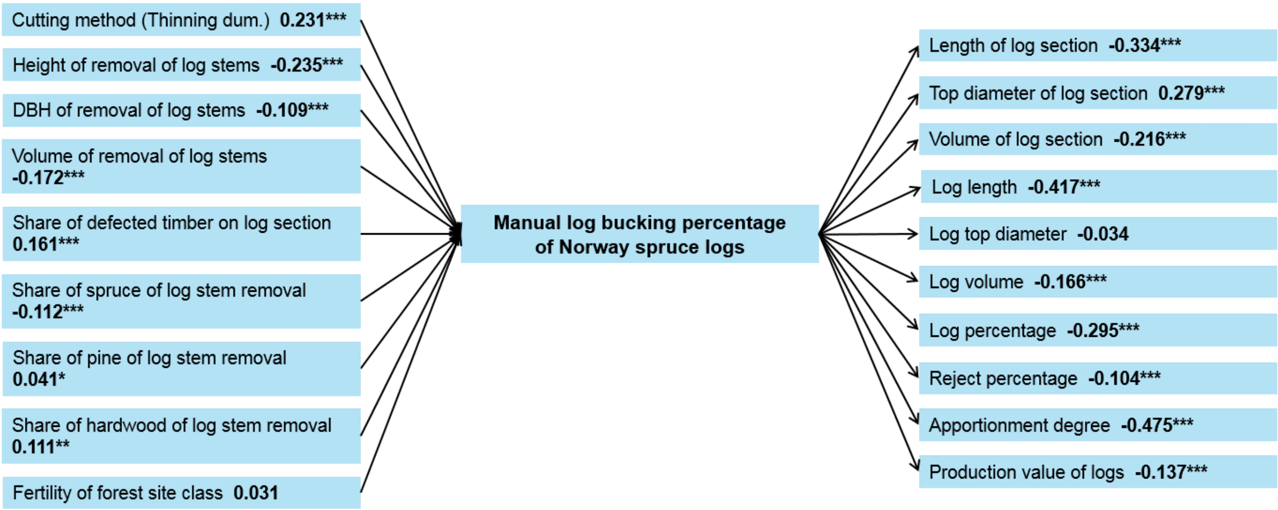

Fig. 5. Spearman's correlations (ρ) and their statistical significances ($p<0.05$; **$p<0.01$; ***$p<0.001$) between the antecedents and manual log bucking percentage, as well as between manual log bucking percentage and the consequences with Norway spruce logs.*

Table 2. Harvesting conditions and classified groups related to the shares of manual log bucking with Scots pine logs.

	Share of manual log bucking (%)			Statistically significant differences between Groups A, B & C
	<60 [A]	60–80 [B]	>80 [C]	
Cutting method (%)				A-C***, B-C***
Regeneration felling	75.3	70.0	60.8	
Thinning	17.1	23.6	32.9	
Other cutting	7.6	6.4	6.3	
Height of removal of pine log stems (m)	18.4	18.2	18.0	A-B***, A-C***, B-C***
DBH of removal of pine log stems (cm)	26.7	26.8	26.3	A-C***, B-C*
Volume of removal of pine log stems (dm^3)	648	643	621	A-B*, A-C***, B-C***
Share of defected timber on pine log section (%)	12.3	15.0	17.4	A-B***, A-C***, B-C***
Share of spruce of log stem removal (%)	60.4	55.2	55.1	A-B***, B-C***
Share of pine of log stem removal (%)	33.5	37.8	35.6	A-B***, A-C*
Share of hardwood of log stem removal (%)	6.1	6.9	9.3	A-B***, A-C***, B-C***
Forest site class (%)				
Upland forest with grass-herb vegetation	17.5	8.6	6.6	
Moist upland forest site	82.5	66.3	78.8	
Dry upland forest site	0.0	25.1	14.6	

DBH = Diameter at breast height ($d_{1.3}$); * $p<0.05$; ** $p<0.01$; *** $p<0.001$.

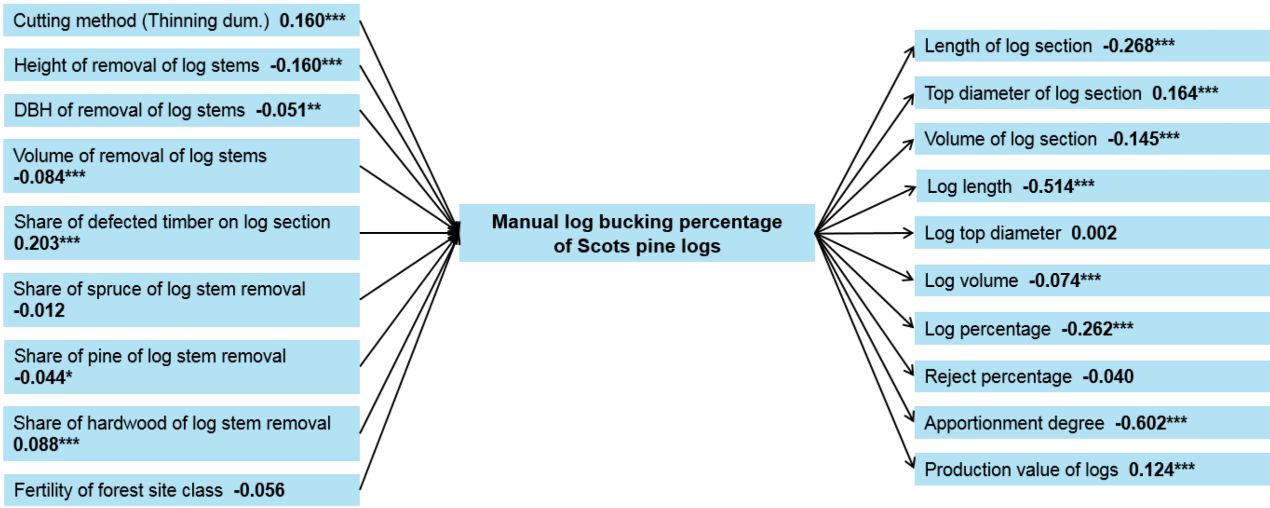

Fig. 6. Spearman's correlations (ρ) and their statistical significances between the antecedents and manual log bucking percentage, as well as between manual log bucking percentage and the consequences with Scots pine logs.

The consequences of the utilization of manual log bucking were significant in the study. When the utilization degree of manual log bucking was high, the utilization of log section with spruce and pine log stems was lower: the length of log section was shorter, the top diameter of log section was thicker, and the volume of log section was smaller (Tables 3 and 4). When using plenty of manual log bucking, the logs cut were also shorter and the volume of logs was smaller. Furthermore, log percentage (i.e. log recovery) was lower on harvesting sites (Figs 5 and 6, Tables 3 and 4).

There was no significant connection between the utilization degree of manual bucking and the reject percentage of pine logs (Fig. 6, Table 4). Nonetheless, with spruce and pine log stems, the apportionment degrees were significantly lower when the shares of manual log bucking were higher (Figs 5 and 6, Tables 3 and 4). When looking at the production value of logs, the relative production value of spruce logs was significantly lower, when the share of manual bucking was high (Fig. 5, Table 3). In turn, the relative production value of pine logs was significantly higher, when the share of manual bucking was high (Fig. 6, Table 4).

Table 3. The consequences of the utilization of manual log bucking with Norway spruce logs.

	Share of manual log bucking (%)			Statistically significant differences between Groups A, B & C
	<30 [A]	30–60 [B]	>60 [C]	
Length of spruce log section (m)	10.9	10.2	8.9	A-B***, A-C***, B-C***
Top diameter of spruce log section (cm)	18.1	18.4	18.9	A-B***, A-C***, B-C***
Volume of spruce log section (dm^3)	550	523	435	A-B***, A-C***, B-C***
Spruce log length (m)	4.96	4.82	4.66	A-B***, A-C***, B-C***
Spruce log top diameter (cm)	22.3	22.4	22.0	B-C*
Spruce log volume (dm^3)	251	247	229	A-B***, A-C***, B-C***
Spruce log percentage (%)	77.2	75.4	71.7	A-B***, A-C***, B-C***
Reject percentage of spruce logs (%)	2.80	2.33	2.10	A-B**, A-C***
Apportionment degree of spruce logs (%)	75.1	69.4	59.0	A-B***, A-C***, B-C***
Relative production value of spruce logs (%) †	100.6	100.3	99.1	A-C**, B-C**

* $p<0.05$; ** $p<0.01$; *** $p<0.001$; † Average relative production value of spruce logs = 100%.

Table 4. The consequences of the utilization of manual log bucking with Scots pine logs.

	Share of manual log bucking (%)			Statistically significant differences between Groups A, B & C
	<60 [A]	60–80 [B]	>80 [C]	
Length of pine log section (m)	10.4	9.9	9.2	A-B***, A-C***, B-C***
Top diameter of pine log section (cm)	18.1	18.4	18.7	A-B***, A-C***, B-C***
Volume of pine log section (dm^3)	486	467	434	A-B***, A-C***, B-C***
Pine log length (m)	4.84	4.79	4.71	A-B***, A-C***, B-C***
Pine log top diameter (cm)	21.4	21.6	21.5	
Pine log volume (dm^3)	225	227	221	A-B*, A-C***, B-C**
Pine log percentage (%)	75.0	72.7	69.8	A-B***, A-C***, B-C***
Reject percentage of pine logs (%)	4.01	3.96	3.52	
Apportionment degree of pine logs (%)	70.0	63.3	52.5	A-B***, A-C***, B-C***
Relative production value of pine logs (%) †	99.1	100.4	100.9	A-B**, A-C***

* p<0.05; ** p<0.01; *** p<0.001; † Average relative production value of pine logs = 100%.

More than a half (55%) of the harvester operators interviewed regarded automatic bucking as significantly better or better than manual bucking to produce the highest bucking outcome with spruce log stems (Fig. 7). Only 11% of the operators believed that the manual bucking causes clearly better or better bucking result than automatic bucking in cross-cutting spruce logs. In cross-cutting pine log stems, 40% of the operators considered that automatic log bucking yields significantly better or better bucking outcome than manual bucking. On the contrary, 29% of the harvester operators estimated that manual bucking produces clearly better or better pine bucking result than automatic bucking (Fig. 7).

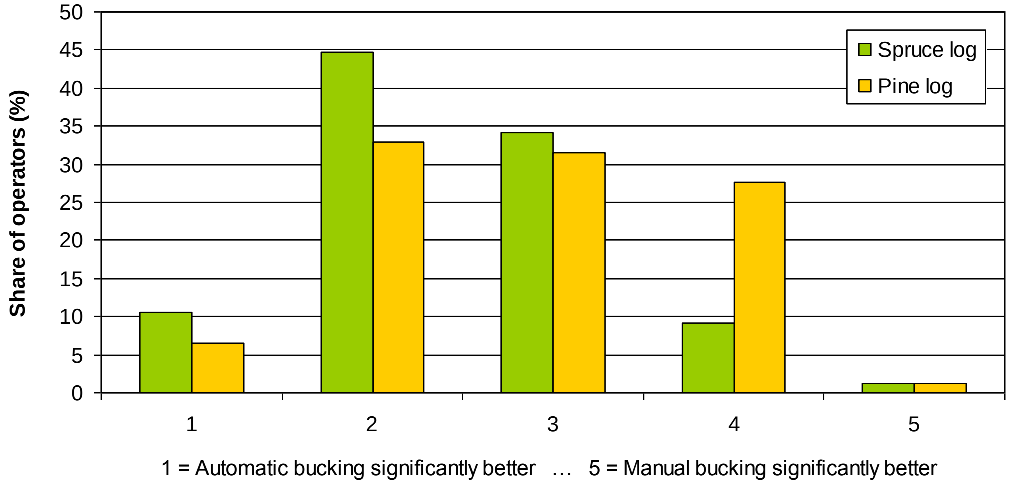

Fig. 7. The estimates of the harvester operators (n=74) interviewed which bucking option (i.e. automatic vs. manual) produces better bucking outcome in cross-cutting spruce and pine log stems.

The high log percentage received the highest weight for the good bucking outcome. Its weight was, on average, 29% with both spruce and pine log stems. Nonetheless, the variation was quite large between the statements among the harvester operators interviewed (Fig. 8). In addition to the log percentage, the operators raised the importance of low reject percentage, the high production value of logs, and high apportionment degree as the elements for the good bucking outcome. The weights of these elements were, on average, 20–25% (Fig. 8). With both spruce and pine log stems, the average weights were at very similar levels.

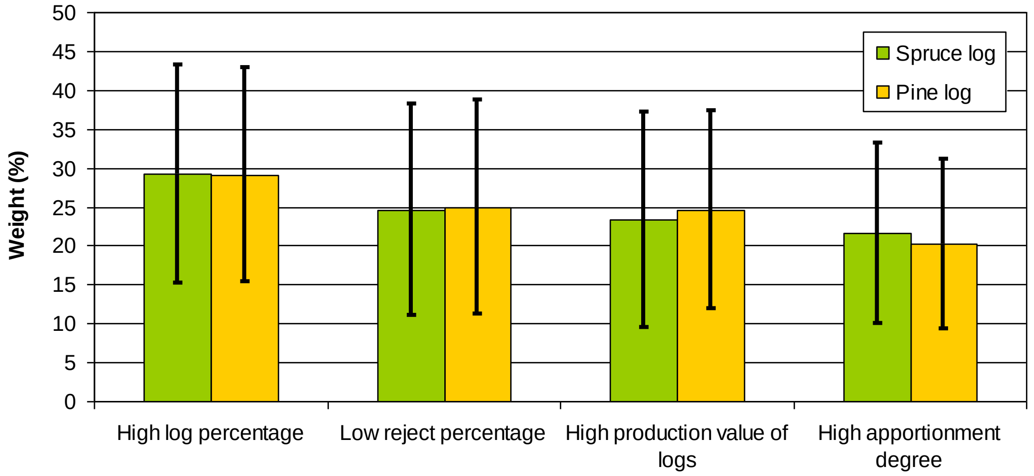

Fig. 8. In the view of the harvester operators (n=74) concerning the weights of the selected elements for the good bucking outcome in cross-cutting spruce and pine log stands. The bars describe the average and the black lines the standard deviation.

The operators told that the most significant reason for using manual log bucking with spruce log stems is rot on log section, mainly on the butt of a stem; then the operator has to sound one offcut piece or several pieces or pulpwood pole(s) from the butt of a stem. With spruce log stems, the second and the third most important reasons for manual log bucking were crook in a stem and defect part on log section, respectively. On the other hand, with pine log stems, the most important reason for utilization of manual log bucking was crook on log section. The second and the third most important reasons were defect part on log section and corkscrew in a stem.

Besides, the harvester operators were asked when they utilize most frequently manual log bucking. The results showed that the operators use manual log bucking most frequently in poor-quality and relative small-sized thinning stands which locate in vigorous forest sites (Fig. 9). Many harvester operators underlined also that the manual log bucking must be applied if target distributions do not work in the log stand. Correspondingly, a little manual log bucking is utilized in high-quality and large-diameter regeneration fellings which are poor in nutrients, as well as on the middle parts of log stems (Fig. 9).

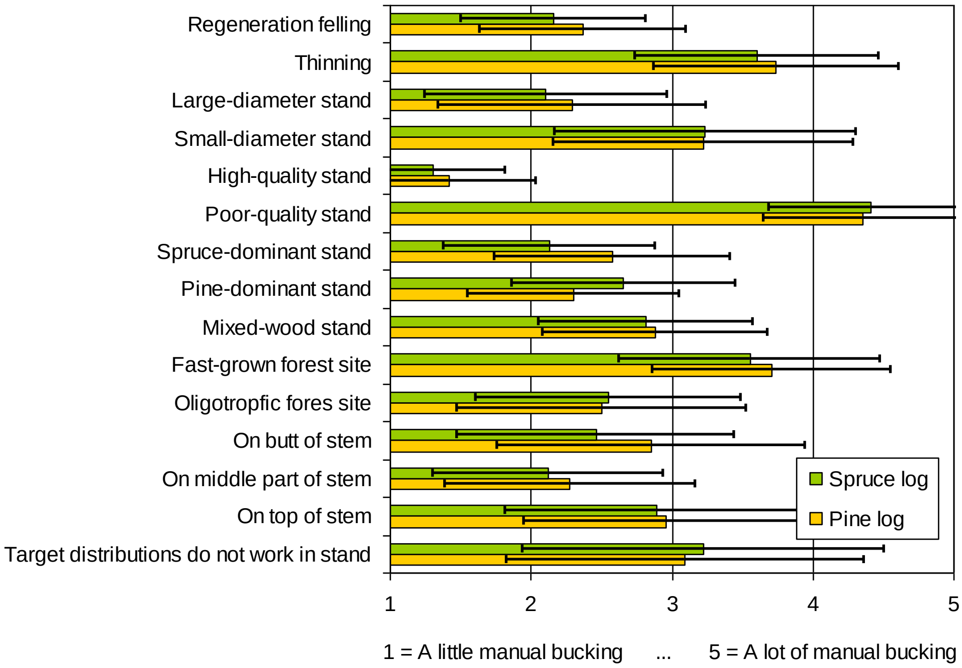

Fig. 9. The evaluations of the harvester operators (n=74) where they utilize a little and where they use a lot of manual log bucking when they are cross-cutting spruce and pine logs. The bars describe the average and the black lines the standard deviation.

The harvester operators were notably willing to take part in log bucking education. Only less than one tenth (8%) of the operators reported that they are not willing to attend bucking education if it will be arranged in the near future. The rest of the operators interviewed were willing to participate log bucking education sessions.

Discussion. The data, particularly the stm data with almost two million softwood log stems and more than four million softwood logs cross-cut for the study was large. Actually, it can be concluded that we had Big Data in the study. On the other hand, the data on the ERP systems was smaller but it can be estimated that also this data gave reliable findings. The manual log bucking percentages for each study operator could not be calculated because the stm data used did not consist of a mark on operator identification information, and there were two operators in many harvesters of the study. Nevertheless, it can be assumed that there was also a significant difference between the harvester operators in the study because there was a large variation between the percentages of manual log bucking in the harvesters of the study (cf. Fig. 4).

The antecedents of manual log bucking were detected in the study. The focus was on the variables of harvesting conditions, i.e. cutting method, the size, defectiveness, tree species of log stem removal, and fertility of forest site class. The results of interview survey displayed also the bucking instructions – among others target distributions – used in the log stand affect the frequency of using manual bucking (cf. Fig. 9). Besides, Änäkkälä [21] has highlighted that a lot of manual log bucking is applied when there are only a few log dimensions (lengths and top diameters) in the target distribution, and in particular the proportions of long logs required are relatively high.

The results demonstrated that there is a strong correlation between manual bucking percentages with spruce and pine log stems by harvesting site and by harvester. This is not a desirable situation when you have to minimize the share of manual bucking with spruce log stems and to maximize the share of manual bucking with pine log stems. Depending on the issue, with which criterion the goodness of bucking outcome is evaluated, two recommendation sets for the present utilization of manual log bucking can be drawn up:

• If the ultimate target for log bucking is to maximize the production value of logs cut, then the study results point out that we have to minimize the manual bucking percentage with spruce log stems and to maximize the manual bucking percentage with pine (Fig. 10).

• If your main log bucking target is some other one (i.e. other than the high production value of logs in cross-cutting), hence it is useful to minimize your manual bucking percentage with both spruce and pine log stems, apart from the reject percentage of spruce logs (Fig. 10).

	Manual log bucking percentage			
	Low	High	Low	High
	Norway spruce		Scots pine	
Length of log section	Longer	Shorter	Longer	Shorter
Top diameter of log section	Thinner	Thicker	Thinner	Thicker
Volume of log section	Bigger	Smaller	Bigger	Smaller
Log length	Longer	Shorter	Longer	Shorter
Log top diameter				
Log volume	Bigger	Smaller	Bigger	Smaller
Log percentage	Higher	Lower	Higher	Lower
Reject percentage	Higher	Lower		
Apportionment degree	Higher	Lower	Higher	Lower
Relative production value of logs	**Higher**	**Lower**	**Lower**	**Higher**

Fig. 10. Summary of the impacts of the manual log bucking percentages of Norway spruce and Scots pine on the selected log bucking results in the study. The green colour illustrates an eligiple log bucking outcome and the red colour an undesirable result.

Whatever the bucking target is, it can be estimated that the manual bucking percentage with spruce log stems must be at a lower level than nowadays. The average manual bucking percentage was 46% with spruce logs in the study. Based on the study results, it can be recommended that the target for the manual log bucking percentage with spruce must be less than 20–30% of the total log volume cut (cf. Table 3). In order to achieve this target, the wood harvesting entrepreneurs and their harvester operators, as well as harvesting officers in wood procurement organizations must be offered the bucking education sessions. – It was great to notice that almost all harvester operators of the study were very willing to participate bucking education if the education will be organized.

Besides, some follow-up studies after bucking education sessions will be needed to clarify what is the progress in the manual log bucking percentages of operators. Likewise, more accurate survey on the reasons (e.g. rot, defected tree section, corkscrew and crook), why the operator utilizes manual log bucking in his/her cross-cutting work, could be carried out in the near future. Namely in the interview survey, the operators was just asked what are the most essential reasons for selecting manual bucking option.

The results showed that the production value and value recovery of pine log stems cut can be increased with utilization of manual bucking. It is a huge potential in the future. Lebelle et al. [22] have also researched the effects of manual and automatic bucking on value recovery in a pine-dominated stand with 22 study plots in Germany. The study results by Lebelle et al. are in line with our findings because they displayed that the value recovery is higher with large-diameter pine log stems when using manual bucking. On the other hand, in the research by Uusitalo et al. [12], automatic bucking of pine log stems did not markedly lower the amount of good-quality lumber compared to quality (i.e. manual) bucking with the study material of 100 sample pine stems.

In addition to the study by Lebelle et al. [22], there is only one other novel bucking research [11] in which the impacts of manual bucking on bucking result have been studied. Holappa Jonsson and Hägglund [11] clarified in Sweden the utilization of manual bucking also in pine stands and noted that there is a significant negative correlation between the utilization degree of manual log bucking and the apportionment degree and that besides there is no significant correlation between manual bucking percentage and the reject percentage of pine logs. Our results are similar with the results by Holappa Jonsson and Hägglund [11] (cf. Fig. 6, Table 4).

Nowadays, harvester operators can conduct a quality bucking with pine log stems. It calls, however, extremely close attention in log bucking work for the harvester operator. It can be assumed that the harvester operator can do very precisely quality (i.e. manual) log bucking with pine stems at the beginning of his/her work shift but at the end of his/her work shift with increased fatigue his/her ability to produce high-quality manual log bucking is at the lower level [cf. 23, 24]. Therefore, in the future, our target must be fully automatic or semi-automatic and harvester computer-aided quality bucking based on the quality grades of the log section zones of log stems with pine and spruce. It will require equipping harvesters with novel mobile laser scanning (MLS) and machine vision (MV) applications [25–27].

The connection between manual log bucking percentage and the productivity of cross-cutting work was not detected in this study. It can be presupposed that when the harvester operator utilizes plenty of automatic log bucking, his/her performance of cutting work is higher [cf. 23, 24, 28]. Lebelle et al. [22] sorted out the influence of automatic and manual bucking on harvesting productivity. The results by Lebelle et al. [22] did not, however, endorse the assumption introduced above but the average harvesting productivity was higher – but not statistically significant – in manual bucking compared to automatic bucking. Nonetheless, the Big Data studies on the effects of using manual and automatic log bucking on cutting productivity will be needed in the future.

The harvester operators interviewed said that the most significant criterion related to the good bucking outcome is high log percentage (Fig. 8). The view of the operators reflects that the operators regard the forest owner of harvesting site as his/her primary customer. In other words, the operator aims to buck the stems so that the log percentage in the stand is maximized, because the price for logs is much higher than the price for pulpwood. Nevertheless, when surveying the criteria for the goodness of bucking outcome in terms of sawmill, the most significant criterion is not log percentage but high-quality logs supplied with high production value and low reject percentage, as well as the realized log matrix meets well target distribution set, i.e. apportionment degree is high. Consequently, harvester operators could be reminded that a sawmill is also their customer and the criteria for log bucking come from sawmills to harvesters and operators. In other words, we have a need of better communication concerning the targets of log bucking in the supply chain of sawmilling industry in the future.

Summary. The study results introduced that the share of manual bucking of Norway spruce logs was, on average, 46% and with Scots pine logs 67%. The harvester operators used manual bucking more frequently in thinning stands with small-sized and defected log stems. On the basis of the study, it can be concluded that if the ultimate target for tree-stem log bucking is to maximize the production value (i.e. value recovery) of logs, then nowadys we have to minimize the manual bucking percentage with Norway spruce log stems and to maximize the manual bucking percentage with Scots pine log stems. In the future, our aim must be fully automatic or semi-automatic and harvester computer-aided bucking based on the quality grades of the log section zones of log stems with Scots pine and Norway spruce. It will require equipping harvesters with novel mobile laser scanning (MLS) and machine vision (MV) applications.

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