The impact of Sitka spruce log dimensions on recovery

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Abstract

The successful running of a sawmill is dependent on the ability to achieve the most profitable combination of throughput and value recovery. Analysis of log type in terms of volume/value recovery and product out-turn are important aspects of the development of optimisation techniques in the sawmill. Typically the breakdown of a stem into sawn products consists of a three-dimensional optimisation process. In the shortwood (or cut-to-length) system, this decision process is spatially and temporally divided into two stages. Based on batch data from 244 daily production runs of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) logs, highly significant relationships were found between dependent variables *output volume* and *output value* and independent variables mean batch *diameter*, mean *batch diameter squared, number of logs* in the batch and *log length* of the batch, for some of the length classes but not for others. The mean batch log diameter had no significant influence on recovery rate, probably indicating that the mix of individual log diameters in the batch, combined with the sawing pattern selection, determines recovery, not the mean batch log diameter value. Further study should focus on an investigation into the relationship between sawing patterns, log size, and product volume and value recovery.

Keywords

Sitka spruce, input/output modelling, wood volume recovery, wood value recovery.

Introduction

The successful running of a sawmill is dependent, *inter alia*, on the ability to achieve a profitable combination of throughput and value recovery. Analysis of volume/value recovery and product out-turns as influenced by log size is an important aspect of the profitable operation. Optimisation of the sawing process, however, cannot be examined in isolation of the cross-cutting process (Reinders 1989). Typically the breakdown of a stem into sawn products consists of a three-dimensional optimisation process. In the shortwood (or cut-to-length) system, this decision process is spatially and temporally divided into two stages: the crosscutting decision and processing at the stump; and the selection of a sawing pattern for each log in the sawmill. In order to move the overall process towards the financial optimum, these two decisions have to be integrated, as the most profitable result will be dependent on the optimal combination of the two.

An integrated optimal cross-cutting and sawing pattern selection strategy has to be selected for each tree. The value and demand for the end-products in the mill

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determine the value and priority of the log sizes that should be considered as part of the log mix during harvesting operations. In the mill, for each log size a number of sawing patterns can be used. Depending on the demand for certain end-products and the availability of the different log sizes in the log yard, a pattern should be selected from those available that are suitable for the specific log/end-product combination. On a day-to-day basis, demand for certain end-products, their availability in inventory, and restrictions on the supply of logs of different sizes to the log yard, may make it necessary to deviate from the optimal sawing pattern in order to produce the required output of specific products.

The sawmilling sector in Ireland

Until the 1960s, the wood-processing sector consisted primarily of a large number of small sawmills, producing non-standardised products. Because production from these plants had difficulty in competing with imported sawnwood, and in the light of forecasted increases in domestic wood supplies, government grant aid was provided for modernisation of the wood processing industry. Over the past 20 years, plantations established just before or after the Second World War have matured and the quantity of wood processed has been rapidly increasing (Gardiner 1991). In 2001 Irish mills processed 2.2 million m^3 of roundwood and this is expected to rise to 3.4 million m^3 by 2015 (Gallagher and O'Carroll 2001). Achievement of the level of processing to date is on foot of an investment programme by the sawmilling industry (ITC 2001).

Recovery

Sawmills can be characterised by the roundwood resource they process, by their size, by the type of machinery used to break down the logs and by the degree of automation (Walker 1983).

Williston (1981) identified a number of factors that determine mill profitability: throughput, volume conversion and grade recovery. Value recovery is maximised where each log is processed such that the greatest volume of the highest value items is recovered at the lowest cost. Steele (1984) pointed out that recovery is determined by the interaction of many variables. These include: log diameter, length, taper and grade, kerf width, product mix, decisions taken by sawmill personnel, the condition of equipment in use in the sawmill, and sawing method. Sawing accuracy is an additional factor influencing recovery (Stern et al. 1979).

Today, most sawmills use optimisation techniques to maximise yield from logs (Todoroki and Rönnqvist 2002). These can have a significant effect on profitability. Todoroki and Rönnqvist (2001) noted that throughout the forest-to-mill supply chain, there are many instances where provision of accurate data can enhance decision-making and profitability. To this end, many software tools have been developed to aid in decision-making, in recovery and ultimately in maximisation of profitability. For example, Barbour et al. (2003) showed in a study using AUTOSAW software, that the financial recovery from small dimension logs could be higher by focusing more on the (high-speed) production of less-valuable 'commercial' and 'factory' lumber than trying to maximise the recovery of high-value 'dimension' lumber, resulting in a slowing down of the production process.

Objectives

The research presented in this paper forms the second phase of a COFORD-funded research project (OptiVal) based at University College Dublin and carried out in conjunction with Palfab Ltd. (Nieuwenhuis et al. 1999). It follows work by Malone (1998) and McHugh (1999), which had the aim to develop a decision support system, incorporating pre-harvest measurement and analysis procedures, that would provide a timber procurer with estimates of the volume, number and diameter class breakdown of log assortments that could potentially be cut from standing lots of mature Sitka spruce (*Picea sitchensis* (Bong.) Carr.) (Nieuwenhuis 2002). Work done by Dooley (2005), investigating the accuracy of harvester head measurements, was also part of the project, aimed at linking all steps in the production chain through a parallel information chain (Nieuwenhuis and Dooley 2006, Dooley et al. 2007). This paper presents the results of a continuation of the project work, focusing on the decision making process in the mill (Browne 2003). The research involved saw pattern selection and value optimisation procedures within the sawmill. The ultimate objective is to develop an integrated decision support system, through the linkage of the in-forest and the in-mill decision making processes into an information chain.

Materials and methods

All data used in this study were collected at Palfab Ltd., Lissarda, Co Cork, and in the surrounding forests. Palfab is a medium-sized softwood sawmill, which purchases over 90% of the logs it processes from standing sales. Logs bought for processing have a small-end diameter (SED) range from 10 to 50 cm. Logs with a SED greater than 50 cm are too large for processing at this mill. Logs enter the yard as shortwood, having been cross-cut in the forest during harvesting. Four log lengths are sawn in the mill: 3.7, 4.3, 4.9, and 5.5 m. Logs of 4.9 m length are the most commonly processed. The mill produces 41 sawn timber sizes in each of the four lengths (Table 1). Timber boards range in size from 3700 x 100 x 14 mm to 5500 x 93 x 229 mm. Large sizes are rarely sawn; smaller sizes make up most of the production. Pallet boards are also sawn to two sizes: 1400 x 140 x 14 mm and 1400 x 95 x 14 mm.

Primary breakdown, re-sawing and sorting

Roundwood is delivered to the mill by truck where it is first weighed. It is then stacked in the yard, with designated areas for different length classes. Production runs typically last a half to a full day, comprising logs of one length. Logs are fed into the mill, one at a time, passing first through a butt reducer and then a debarker. Logs then pass through a scanner and onto a log angle rotator, which positions them for sawing.

The sawing line setup in the mill was as follows: logs passed through the first saw twice, removing sideboards to produce rectangular cants, which were broken down

Table 1: Product codes by width and thickness. Sawn and notional sale dimensions are shown.

Product code	Width	Thickness	Product code	Width	Thickness
	mm			mm	
1	102/100	14/14	22	229/225	22/22
2	36/35		23	36/35	
3	45/44		24	45/44	
4	75/75		25	75/75	
5	117/115	36/35	26	102/100	22/22
7	127/125	36/35	28	127/125	50/50
8	45/44		29	117/115	55/55
9	75/75		30	152/150	57/55
10	152/150	14/14	31	162/160	63/62
11	22/22		32	192/190	63/62
12	30/30		33	302/300	75/75
13	36/35		34	102/100	102/100
14	45/44		35	106/105	102/100
15	75/75		36	127/125	127/125
16	177/175	22/22	37	152/150	152/150
17	36/35		38	156/155	152/150
18	45/44		39	202/200	202/200
19	75/75		40	132/130	36/35
20	202/200	45/44	41	229/225	92/90
21	75/75	75/75			

into boards, these were then trimmed to a set length. Boards were automatically sorted into pre-assigned sizes. Sideboards were processed into pallet wood, which was also trimmed and sorted.

Data collection, storage, retrieval and analysis

In order to carry out the analysis of log size in terms of end-products and volume/value recovery, a number of preliminary studies had to be carried out. First, the reporting capabilities of the production control computer had to be examined. After establishing and analysing the range of report formats available, the accuracy of the reporting process was established by comparing manually collected data sets with those produced by the computer. Data from the production control computer could not be transferred to another computer electronically and had to be printed and manually entered into a spreadsheet.

It was decided that one year's production data were needed to produce accurate statistical results. This was on the basis that within the space of one year all log and end-product sizes would be covered. A year's data also covered differences in log quality and/or mill procedures between summer and winter. Data were in the form of computer-generated production reports for each day the mill was in operation. Pallet wood production data were produced manually at the stacking line. Reports contained information on the product dimensions, the number of boards per batch, the number of batches and the total volume of pallet wood produced during the day. All diameter values are based on under-bark measurements.

A spreadsheet was developed to facilitate data entry and validation. It comprised details of all logs processed and boards produced. A completed and validated data set was used for statistical analysis, using a General Linear Model (GLM) SAS procedure for variance and regression analyses.

The overall hypothesis tested was that the output volume and value of a batch were functions of a range of input parameters such as the mean diameter of the trees in the batch, the mean cross section of the trees, the log length of the batch and the number of logs in the batch. A range of models was analysed; in all of these models, batches of logs (as opposed to individual logs) were the units analysed. In the first set of models, relationships between the dependent variable *output volume* (m^3) and *output value* (€) for the batch, and independent variables mean *diameter* of the logs in the batch, *number of logs* in the batch and *log length* of the batch were investigated for batches of all log lengths combined. In the second set of models, these relationships were analysed for each length class separately. Output volume was calculated by summing the volumes of all products produced from the batch, while output value was calculated by summing the monetary values of these products.

Results

Log dimensions

The overall production period covered was 244 days, which represents the 1-year duration that the data set covers. The 4.9 m log length dominated production, with 153 days (Table 2).

A large number of product sizes was produced, with different products arising from combinations of different lengths and dimensions. Product codes were used to represent specific dimensions (see Table 1). An analysis of the length and diameter distribution of the logs processed revealed that logs in the SED class 180 mm were the most frequently processed log size for all log lengths, except for the 5.5 m length class, where logs in the SED class 250 mm were most frequent.

Table 2: Number of days and percentage of total time during which different log lengths were cut.

Log length *m*	*Number of days*	*% of total number of days*
3.7	39	15
4.3	24	10
4.9	153	63
5.5	28	11
Total number of days	244	100

The average SED of all logs sawn over the 1-year period was 21.4 cm. The average SEDs for each length class are presented in Table 3. A much wider range in SEDs was present in the 4.9 m length class than for the remainder of the length classes.

Table 3: Average small end diameter (SED) and SED range for each length class.

Log length *m*	*Average SED* *cm*	*Range* *cm*
3.7	20.6	19.0 – 23.8
4.3	20.9	19.0 – 22.2
4.9	21.5	18.6 – 33.6
5.5	23.5	19.5 – 26.2

Volume recovery

Based on the full data set, daily percentage recoveries were determined by dividing daily volume production by daily roundwood volume consumption. All recoveries are based on under-bark volumes. Analysis of batch recoveries on a length class basis indicated a very constant recovery rate for each length class, independent of the mean SED value. After omitting four outliers, average recovery percentages for each length class were as follows: for 3.7 m 55%, for 4.3 m 57%, for 4.9 m 60% and for the 5.5 m length class 58%.

Product dimensions

Following analysis of the numbers and dimensions of the logs processed and the recovery rates obtained, the number of products cut in each product code (see Table 1) and length class were analysed (Figure 1). Products 3 (102 x 45 mm), 13 (152 x 36 mm) and 24 (229 x 45 mm) were the most commonly cut, with a large proportion of 4.9 m logs processed into these sizes. Products 14 (152 x 45 mm) and 24 (229 x 45 mm) were frequently cut from 5.5 m logs, while 3.7 m logs were most often converted into product 2 (102 x 36 mm). Products 2 (102 x 36 mm), 3 (102 x 45 mm), 7 (127 x 36 mm) and 14 (152 x 45 mm) were cut most often from 4.3 m logs.

Analysis of the log input/recovery relationships

Based on the batch data for 244 days, relationships were examined between two dependent variables, output volume and output value, and a number of independent variables, namely diameter, diameter squared, number of logs, log length, and product dimensions produced. Where statistically significant relationships were found, regression coefficients are presented.

<u>Output volume and output value, as functions of number of logs, length and diameter</u>

In the first models, the relationship between the dependent variables output volume and output value and the independent variables, number of logs processed, diameter and log length was investigated for the full data set. A highly significant relationship

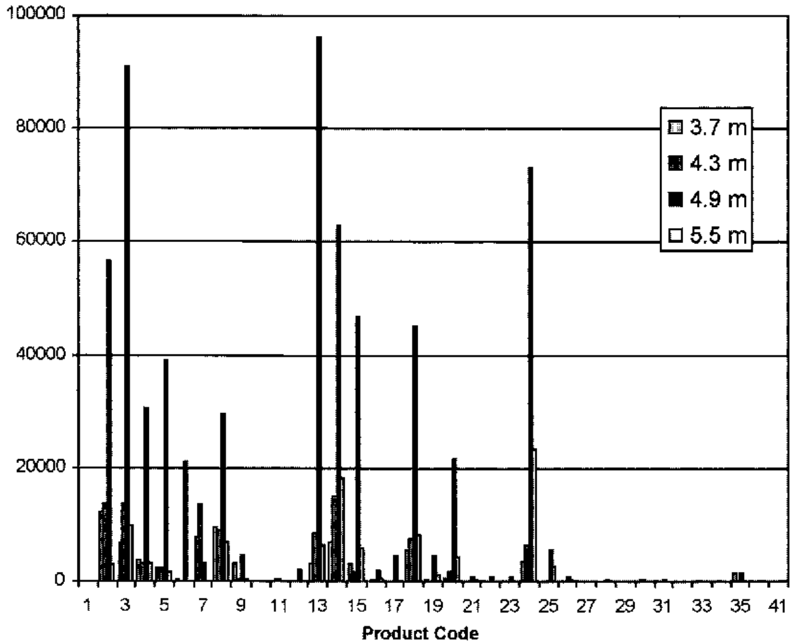

Figure 1: Number of products, by length class (3.7, 4.3, 4.9 and 5.5 m) and product code (see Table 1).

was found between the dependent and independent variables, both for output volume and for output value with p≤0.01 (Table 4).

Output volume and output value, as functions of diameter, diameter², and number of logs

Having analysed the relationships between *output volume* and *output value* and the independent variables for all the length classes combined, these relationships were investigated for each length class separately. The data set was sorted by log length and the analysis was repeated for each of the data subsets with the independent variable *log length* (L) removed from the models (Tables 5 and 6).

Table 4: Regression statistics for the relationship between dependent variables output volume and output value and independent variables diameter, number of logs and log length, for the full data set. Standard errors of estimates in brackets.

Model	*F value*	R^2	*Intercept*	*Diameter mm*	*Number of logs*	*Length m*
Output volume m^3	1266.9*	0.94	-346.17* (13.87)	0.83* (0.072)	0.13* (0.0037)	40.59* (2.60)
Output value €	1047.8*	0.93	-59358.86* (2426.1)	143.85* (12.57)	20.06* (0.65)	6987.19* (454.3)

* significant at p≤0.01 level

All models were highly significant. In the *output volume* models for the 3.7 m and 4.9 m length classes very high R^2-values were obtained and the regression coefficients were highly significant (Table 5). In the *output volume* model for the 4.3 m length class a very high R^2-value was obtained but only the independent variable *number of logs* was highly significant. In the *output volume* model for the 5.5 m length class a lower R^2-value was obtained than in the other models and only the independent variable number of logs was highly significant. Similar trends were found for the *output value* models (Table 6) as for the *output volume* models presented above.

It should be noted that the coefficients for the *output volume* (Table 5) and *output value* (Table 6) models for the 3.7 m length class are distinctly different (i.e. a change of sign for the intercept and the coefficients for *diameter* and *diameter*^{2}) from the comparable coefficients in the models for the other length classes.

Table 5: Regression statistics for the relationship between dependent variable output volume (m^3) and independent variables diameter, diameter^2 and number of logs, for each length class separately. Standard errors of estimates in brackets.

Length class *m*	*F value*	R^2	*Intercept*	*Diameter* *mm*	*Diameter*^{2} *mm*^{2}	*Number of logs*
3.7	797.9*	0.98	744.666*	-7.788*	0.019*	0.112*
			(170.20)	(1.62)	(0.004)	(0.003)
4.3	333.9*	0.98	-721.457	5.454	-0.009	0.116*
			(643.57)	(6.29)	(0.015)	(0.007)
4.9	528.2*	0.91	-764.031*	5.913*	-0.010*	0.142*
			(52.53)	(0.44)	(0.001)	(0.004)
5.5	10.8*	0.57	-375.164	2.427	-0.002	0.159*
			(736.91)	(6.40)	(0.014)	(0.031)

* * significant at p≤0.01 level

Table 6: Regression statistics for the relationship between dependent variable output value (€) and independent variables diameter, diameter^2 and number of logs, for each length class separately. Standard errors of estimates in brackets.

Length class *m*	*F value*	R^2	*Intercept*	*Diameter* *mm*	*Diameter*^{2} *mm*^{2}	*Number of logs*
3.7	691.1*	0.98	133526.3*	-1384.5*	3.525*	17.455*
			(28637.7)	(271.9)	(0.64)	(0.50)
4.3	245.6*	0.97	-117411.2	881.2	-1.481	17.657*
			(118127.9)	(1155.2)	(2.80)	(1.34)
4.9	476.8*	0.90	-132734.0*	1025.8*	-1.825*	22.180*
			(8660.9)	(71.9)	(0.15)	(0.69)
5.5	8.9*	0.52	-69794.839	460.271	-0.543	25.100*
			(132157.2)	(1147.1)	(2.49)	(5.61)

* : significant at (Pr>F) <0.01

Discussion

The reporting capabilities of the production control system in the sawmill were investigated and a test on the accuracy of the reporting process was carried out in order to ensure that the data collected from the production control system was suitable for use as part of the main analysis stage.

As the accuracy of the data produced by the production control system was tested and found to be acceptable (Browne 2003), data were obtained from the system. Recovery from each length class was on average over 55%. The recoveries are in line with recovery percentages in other mills, which ranged between 55 and 60 % (Williston 1988). In a study of a pallet mill by Dooley (2003) the average recovery was 50.6 %. This lower value was judged to be the result of the small diameter of the logs processed.

Recovery increased with increasing log length but fell slightly for the 5.5 m length class. The most likely reason for this reduction is the combined effect of log length and taper. Steele (1984) found a strong correlation between increasing log length and decreasing recovery, especially for logs longer than 17 feet (5.1 m). Steele also found a close relationship between increasing taper rate and reduced recovery for logs of similar small end diameter. Both these findings are likely explanations for the reduction in recovery to 58% for the 5.5 m log class as compared to the 60% rate for the 4.9 m length class.

A highly significant relationship between the dependent variables *output volume* and *output value* and the independent variables *number of logs*, *diameter* and *length* was found. Analyses of the relationship between *output volume* and *output value* and independent variables *diameter*, *diameter*^{2} and *number of logs* were carried out. The 3.7 m and 4.9 m length classes produced highly significant relationships and very high R-squares. As regards the 4.3 m length class, a high R^2 was found but the parameters were not significant. The 5.5 m length class produced a lower R^2 result. A number of possible reasons may explain the findings in the 4.3 m length class and the 5.5 m length class. For both these length classes small data sets were available consisting of only 24 observations for the 4.3 m length class and 28 for the 5.5 m length class. It may also have been the case that a narrower or wider range of sawing patterns was used for these length classes. Future analysis of sawing pattern selection may confirm this.

The above models will form the basis for a decision support system for the mill. However, during the course of the research reported in this paper, it was not possible to analyse the impact of individual sawing patterns on volume and value recovery due to limitations in data collection opportunities and the specific processes used in the mill. In Palfab, timber entering the mill is unsorted by diameter and the saws are reset for every log. This means that a different sawing pattern was used for each log and, with the computer system not recording individual sawing patterns, it was impossible to collect the necessary data and to analyse the impact of pattern selection on volume and value recovery at this stage of the study. However, it is envisaged that this analysis will have to be carried out in the future in order to finalise the decision support system as set out in the objectives of the study. In addition, the effect of factors such as taper, sweep and ovality, on the recovery in the sawmill need to be investigated.

Conclusion

The research reported was directed at investigating the impact of size (log length and diameter) of Sitka spruce logs on product volume/value recovery. Based on the analysis carried out, it can be concluded that output volume and output value are functionally related to a range of independent parameters for the 3.7 and 4.9 m length classes. Volume recovery rates were similar to rates found in other sawmills. The highest rate (60%) was associated with the 4.9 m length class.

The models developed in this study will form the basis for the decision support system for the mill as set out in the objectives of this study. This will allow the sawmill manager to predict potential volume and value out-turn for a range of log sizes. Work should be carried out on the relationships between sawing pattern, log size, and volume and value recovery.

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