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Sawing simulation of *Pinus pinaster* Ait.

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ABSTRACT

The paper deals with the sawing simulation of Maritime pine (*Pinus pinaster* Ait.) and is a report from a project aiming to increase the knowledge in how different raw material characteristics and sawing factors are affecting on the sawing yield of Maritime pine. The conversion was executed by an integrated optimising software system, WooDCIM® developed at VTT - Technical Research Centre of Finland, and was used to predict the value yield in the sawing process.
The study was based on a sample of 35 maritime pine stems randomly sampled from 4 different sites in Portugal. Based on scanning of boards and mathematical reconstruction algorithms, 3D and 2D representations were obtained for logs and stems allowing the determination and visualisation of external shape as well as of the internal knot architecture. This provides input data set for sawing simulation software for converting logs into end products. Input data concerning final products and process variables was obtained directly from the wood based industry.
The effect of some parameters on the volume and value yield of maritime pine stems was studied. Parameters include log dimensions and position within the stem, dimensions and grades of sawn timber products and saw kerf. Results were obtained through a set of simulations using different input variable combinations.
The WoodCIM® sawing simulation software has shown potential to optimise the operating instructions in the sawing process of Maritime pine and to clarify the influence of the different raw material characteristics and production parameters on the recovery of sawn timber. Virtual sawing results were close to those realised in practice when similar situations were compared.

INTRODUCTION

For an efficient raw material utilization with the best possible economical results, the wood conversion chain has to be closely integrated and optimised in its different parts. In the sawing process, yield may be investigated using three alternatives : company's statistics, trial sawing and simulations. In the practice there is always possible to carry out only limited test sawing and empirical work, which is also expensive. It is also very difficult to establish two or more exactly identical log sets and correspondingly it is difficult to keep exactly two identical processing parameter values by sawing different sets of logs. Statistics provide possibility only to analyse what has happened in the past. These are the reasons why a simulation approach is useful : information for management, decision-making and process control is provided based on mathematical models and software tools to simulate production situations.
Progress in scanning technology, defect detection and algorithms for virtual reconstruction of logs allowing the study of internal tree structure i.e. knot, heartwood and resin pockets (Oja, 1997 ; Björklund, 1999 ; Pinto *et al.*, 2003) have provided support to improve optimisation and simulation procedures.
Sawing simulation software always require extensive input data concerning products, sawing process as well as wood raw material. In some cases, data are derived from the measurement of actual logs (Tsolakides, 1969 ; McAdoo, 1969 ; Cummins and Culbertson, 1972) and simulation of virtual logs is done using computer graphics (Richards, 1973 ; Pnevmaticos *et al.,* 1974 ; Todoroki, 1988, 1990). In other cases, a growth modelling approach is used and tree models representing external and internal stem features are the input data (Leban and Duchanois, 1990 ; Meredieu *et al.,* 1999 ; Lönner and Björlund, 1999). Several research teams have developed computer programs, using input data based on scanning of logs or boards and reconstruction algorithms producing a 3D description of log/stem concerning its internal defects and shape, either derived from computer tomography (Occena and Schmoldt, 1996 ; Schmoldt and Araman, 1996 ; Chiorescu and Grönlund, 2000) and scanning of boards (Åstrand and Rönnqvist, 1994 ; Usenius and Song, 1997 ; Usenius, 1999, 2000).

Since the early 1970, the Wood Technology group at VTT (Technical Research Centre of Finland) has developed simulation and optimising computer software systems for the mechanical forest industry to increase the value yield and the profitability of wood converting companies (Song, 1987 ; Usenius, 1999, 2000). An integrated optimising software system, VTT-WoodCIM® , was developed that can be linked to the product and material flow control system or other computer systems at the sawmill. It consists of the following software modules :

- software for optimising selection of stands and bucking of stems,
- program for optimising the limits of sawlog classes,
- simulation program for predicting the value yield in sawmilling,
- software for optimising manufacturing components,
- sawing model based on linear programming.

For this study the WoodCIM® software was used to predict the volume and value yield in sawing, using the conversion of virtual reconstructed logs into wood products. The programme needs as input : accurate geometry of logs, geometry, quality and position of knots in the reconstructed logs, nominal and green dimensions of sawn timber products, quality requirements for each face of the sawn timber products, prices of sawn timber products and of by-products, saw kerfs, and sawing dimensions, lengths and grades.

The simulation programme calculates the sawing yield by using different sawing set-ups for each log and choosing the best combination of sawing pattern and dimensions and qualities of the sawn timber products. The results can be obtained for the entire batch of logs, for the logs from a stem or for individual logs and the output consists of the best set-up and sawing pattern, the number of sawn timber products by dimension and grade and the volume and value yield of sawn timber products.

The focus of this study is to predict the outputs of sawing components for Maritime pine (*Pinus pinaster* Ait.) using virtual logs, reconstructed from scanning images of boards and the sawing simulation of WoodCIM®. The programme was used to study the influence of raw material characteristics and production parameters on the recovery of Maritime pine sawn timber components and further to supply information to be included in real time simulation programmes. The procedures to adapt the existing software to Maritime pine, based on a set of 35 pine stems collected from four representative stands in Portugal, are described and its potential and limitations are discussed. The simulated volume and value yields are compared with recorded yields in industrial sawing.

Pinus pinaster Ait. is an important softwood for Southern Europe, covering over 3 millions ha in Portugal, Spain and France, directed to the pulp, board and sawmilling industries. In Portugal, the sawmilling industry consumes about 70% of the annual wood yield (CESE, 1996). A better knowledge of raw material characteristics and the implementation of value yield optimising software will allow a better exploitation of Maritime pine and hence an increase in the industry's competitiveness.

MATERIAL AND METHODS

Tree sampling

Thirty five maritime pine (*Pinus pinaster* Ait.) trees were randomly sampled from 4 stands in Portugal : Leiria (S1), stated owned, Mação (S2), Alpiarça (S3) and Marco de Canavezes (S4), private forest. Table 1 shows the location and main geographic and climatic conditions of each site.

Table 1 : Site characterisation.

	S1	S2	S3	S4
Coordinates (1)	08º 55’ 55" W 39º 45’ 02" N	07º 59’ 49" W 39º33’14" N	08º 35’ 05" W 39º 15’ 36" N	08º 08’ 55" W 41º 11’ 08" N
Mean air temperature (ºC)	12.5-15	15-16	16-17.5	12.5-15
Relative air humidity (%)	80-85	75-80	75-80	75-80
Annual rainfall (mm)	600-700	500-600	500-600	700-800
Total radiation (Kcal/cm2)	140-145	150-155	145-150	145-150

(1)WGS84

After harvesting, total height, crown height and height of the first visible dry branch were measured. Two cross diameters (N-S, W-E) were measured every 2.5 m along the tree and bark thickness was determined with a bark gauge in the position of largest thickness. Table 2 shows the biometric data for the sampled trees.

Table 2 : Biometric characteristics of the sampled maritime pine trees (mean and standard deviation in parentheses) and site index.

	S1		S2		S3		S4	
Age	83 years		43-55 years		42-55 years		48-55 years	
Number of sampled trees	20		5		5		5	
Total height (m)	28.8	(2.8)	15.7	(3.4)	21.3	(1.0)	24.1	(1.0)
Crown height (1) (m)	8.7	(2.6)	7.7	(3.5)	9.1	(1.9)	10.0	(2.0)
Height to first dry branch (m) (2)	16.0	(2.1)	7.7	(1.2)	7.8	(1.3)	8.0	(1.6)
DBH (cm)	47.8	(7.3)	28.0	(2.3)	38.9	(9.2)	42.7	(5.3)
Bark thickness at DBH	3.4	(0.7)	3.2	(0.9)	3.5	(1.0)	4.1	(0.8)
Volume over bark (m^3) (3)	2.7	(0.7)	0.5	(0.1)	1.3	(0.6)	1.6	(0.1)
Volume under bark (m^3) (3)	2.3	(0.6)	0.4	(0.0)	0.9	(0.4)	1.2	(0.2)

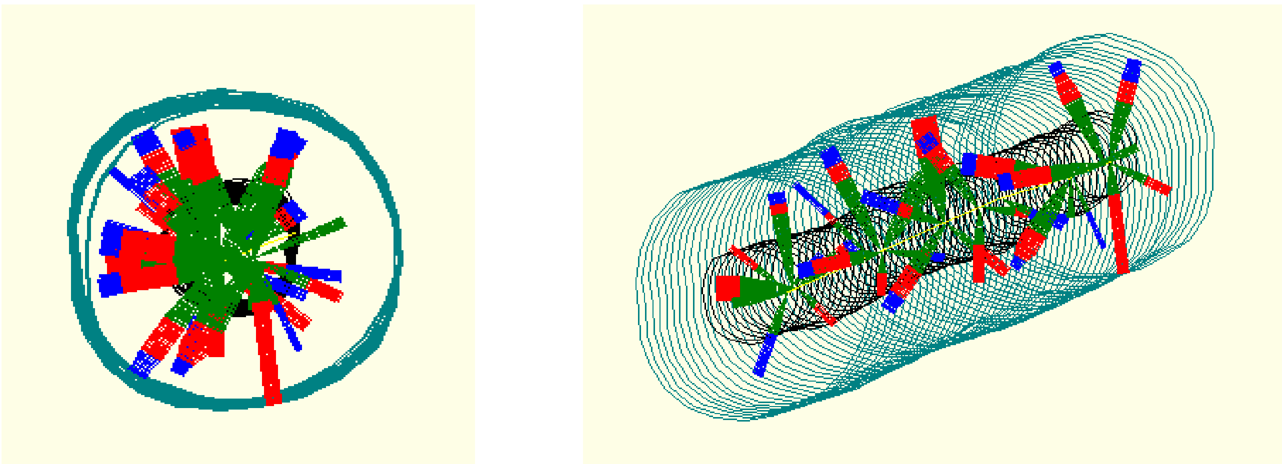
(1) Crown height = total height - live crown base height ; crown base at the simultaneous occurrence of 2 green branches ; (2) Height from tree base to the first visible dry branch ; (3) Precise cubic method, Smalian formula.

Sawing simulation

The sawing simulation software of WoodCIM® was used to estimate the production of lumber and boards. The software module used is flexible, subject to modifications to match the requirements for the adaptation to a new species and processing conditions and allows the free specification of product dimensions and qualities, concerning size and number of knots. The software was reconfigured for Maritime pine, i.e. in the input data the number of sawing patterns was increased up to 100 and the number of widths allowed to each sawn product was also increased.

Input raw material for virtual sawing

The wood raw material used in this study for the sawing simulations is a set of virtual logs, which are mathematically reconstructed logs based on the so-called flitch method. The sample trees were cross cut into a total of 133 logs and live sawed into 25 mm thick flitches. The flitches were scanned using WoodCIM® camera system providing RGB (colour component) information stored in the computer files for further processing and analyses. The measured data was computed by VTT's PuuPilot software showing the image of the flitch on the screen. The data concerning the geometrical and quality features of the flitch was processed with a dedicated software producing a mathematical reconstruction of a log or of a stem in xyz-co-ordinate system (Song, 1987 ; Song, 1998). 3D and 2D representations were obtained for logs and stems (Fig. 1) allowing the visualisation of external shape as well as of the internal knot architecture, including its quality (sound, dry or rotten knot). The reconstructed logs include also a 3D visualisation of the heartwood. The position in the tree as well as the compass orientation is known for all logs.



a b

Figure 1 : Mathematically reconstructed log of maritime pine showing the geometry of the log, the internal knots and heartwood in 2 (a) and 3 (b) dimensions.

In the description of log external shape the reconstruction gives as output 24 radial vectors per each cross-section of the log with 20 mm between neighbouring cross-sections. Taper was calculated for each log from the slope of the line marking the external limit of diameters determined every 50 mm of length. The diameter is the average of all vectors that define each cross-section. Pith curviness is the maximum deviation (in any direction) of pith found along the log in relation to an imaginary axis of a straight pith.

The entire stem can be reconstructed by joining its different reconstructed logs and this virtual stem can then be cross cut into any desired log length. For this study the 35 maritime pine reconstructed stems were cross cut into a total of 218 logs with 2.6 m length. This length was set according with the Portuguese sawmill industry information, as it represents around 90% of the log length consumed.
Table 3 shows the log characteristics. The top diameters of the 218 sawn virtual logs varied between 91 and 530 mm, with 65% within 200-300 mm. The simulation results concern a total of 216 logs since two logs were not virtually sawn because their diameter was too small for the given sawing pattern.

Table 3 : Average and range of values for log top diameter, taper and pith curviness according with origin.

		S1	S2	S3	S4
Number of logs		138	20	27	33
Diameter (mm)					
	Range	180 - 530	91 - 198	133 - 391	129 - 341
	Average	319.6	154.2	221.1	242.6
Taper (mm/m)					
	Range	1 - 30	1 - 24	1 - 46	1 - 31
	Average	9.3	9.8	12	10.8
Pith curviness (mm)					
	Range	0 - 65	10 - 52	1 - 97	10 - 108
	Average	14.5	25	21.8	34.8

Input process parameters

The input data used in the simulations concerning product dimensions, quality, prices and sawing patterns were obtained from a Portuguese sawmill industry**.** The simulations were done for lumber with 50 and 70 mm thickness and 100 mm width and boards with 25 mm thickness and widths from 100 to 200 mm. The length of all sawn products was 2.5 m. No wane edge was allowed in any sawing product. Only green dimensions were used so the results are green sawing yields. Sawkerf was 2.5 mm for the live-sawing.
For sawing lumber and boards, 35 different sawing patterns were given as input (lumber products taken from the middle of the log and boards from sides). The programme tries all the sawing patterns for the given log diameter and chooses the one that results in the best value yield.
Regarding the quality of sawn timber products, the programme uses as input specification the number and size of knots allowed in each of the four faces of the component. Three grade classes were considered for boards (Tab. 4) in relation to the presence of defects in the two wide faces of the boards. The narrow faces of boards and lumber pieces had no restrictions.

Table 4 : Quality grades of boards used in the simulation.

	Wide face 1	Wide face 2
Grade 1	maximum 1 sound knot	maximum 4 knots (sound or dry)
Grade 2	maximum 4 knots (sound or dry)	no restrictions
Grade 3	no restrictions	no restrictions

RESULTS AND DISCUSSION

Raw material characterization

The overall top diameter distribution for the 216 logs is shown in Figure 2. A large between log variation was found, with logs ranging from 50 mm to 500 mm top diameters. Most logs were included in the 30-35 cm (24%), 25-30 cm (21%) and 20-25 cm (20%) diameter classes.
The trees sampled showed different sizes in the four stands (Tab. 2) from which resulted logs with different average characteristics (Fig. 3). In the state-owned Leiria forest (S1), management is oriented to produce wood raw material for high added value timber products. Silviculture consists in 5-year rotation thinnings between 20 and 40 years of tree age, pruning before the first thinning and clear cutting at an approximate age of 80 years (Gomes, 1999). Therefore, from the set of logs used in this study, the logs from Leiria (S1) showed the highest average top diameter and lowest taper and pith curviness (Fig. 3). These logs are probably a part of the best quality fraction available in Portugal for the sawmilling industry.
In the private-owned Portuguese pine stands (S2, S3, S4) rotation is about 40-50 years. In most of the cases there are no cultural operations and no cleaning of undergrowth vegetation. Site 2 showed the worst site growth and the logs obtained from the sampled trees had the smallest diameters (Fig. 3).

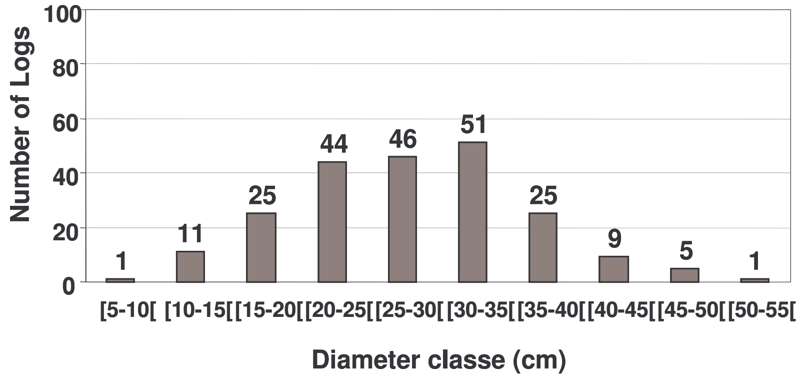


Figure 2 : Number of virtual logs classified by top diameter.

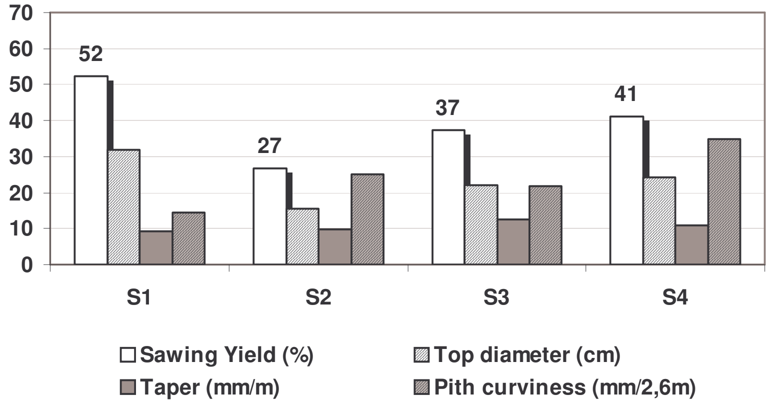


Figure 3 : Average top diameter, taper, pith curviness and volume yield of sawn timber products from logs from the different sites.

Sawing yields

The overall average volume yield in the simulated sawing of 216 logs was 51%, if no specific quality requirements or prices were defined. When considering logs classified by top diameter class (Fig. 4), the volume yield increased with diameter with maximum values of 59% corresponding to the sawing of logs in the 40-45 cm and 45-50 cm diameter classes. The smallest diameter class yielded only 14% in sawing products.

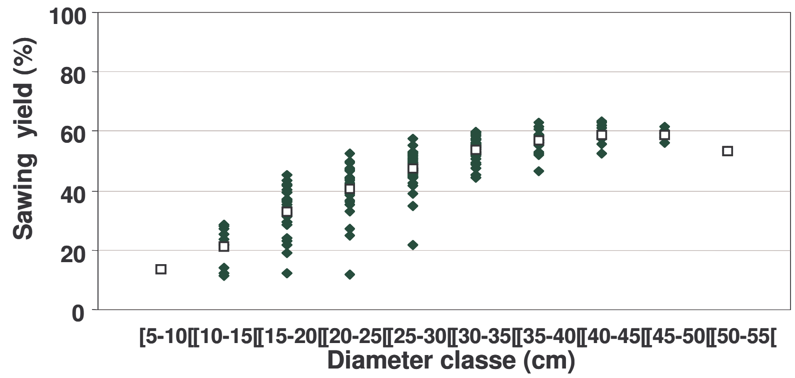


Figure 4 : Yield of sawn products and average log yield by top diameter classes.

The variability of the values inside each class is high, especially in the range of diameters between 10 and 25 cm due to the variability in log taper and curviness as well as due to the different origin of the trees. Figure 3 shows the yield of sawn timber products, top diameter, taper and pith curviness values for the logs from the 4 different sampled sites.

The best sawing yield (52%) was obtained with the logs from Leiria (S1) in accordance with the larger diameters and lower pith curviness and taper when compared to the other stands (S2, S3 and S4). The lowest sawing yield of only 27% of sawn products was obtained for the S2 logs, which had the smallest diameters.

Value optimised sawing yields

Figure 5 shows the yield of sawn timber products when the sawing simulations were executed considering quality grades for the boards (value optimised) and compared with the yields obtained without quality specification (volume optimised).

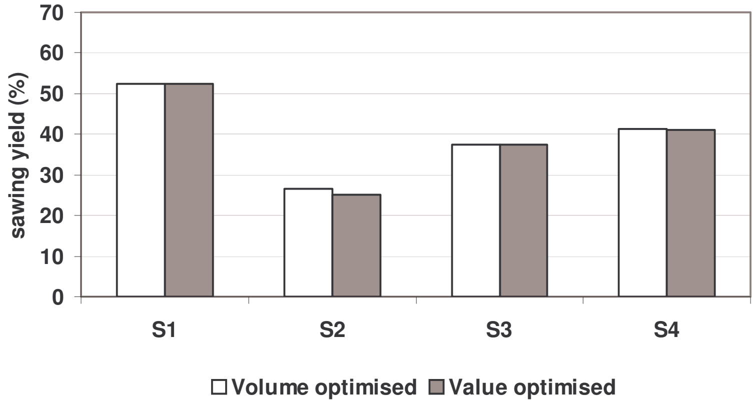


Figure 5 : Yield of sawn timber products when the sawing simulation is executed value or volume optimised.

The overall sawing yield decreases with the introduction of quality specifications of the boards (51.6% vs. 50.9%). The differences are not very high and only noticeable in the smallest logs from site S2 (Fig. 5). In fact in the sawing patterns used in the simulations, boards were sawn from the outer parts of the log while lumber was taken from the inner part containing most of the knot core. Therefore, for the larger logs, the sawing pattern selected by the programme when quality specifications for boards were introduced in the input data was the same, or very similar, to the pattern selected without quality specifications. For logs with smaller diameters, the differences in sawing yields will be higher as most of these are top logs in the stem with a larger knot core.
The average economic value of sawn products, sawdust and chips obtained per cubic meter of raw material, is shown in Figure 6 for each log diameter class. The obtained value yield increases strongly with log diameter class from a low value of 35 €/m^3 for the 5-10 cm diameter class to 105 €/m^3-107 €/m^3 for the 40-45 and 45-50 cm diameter classes.

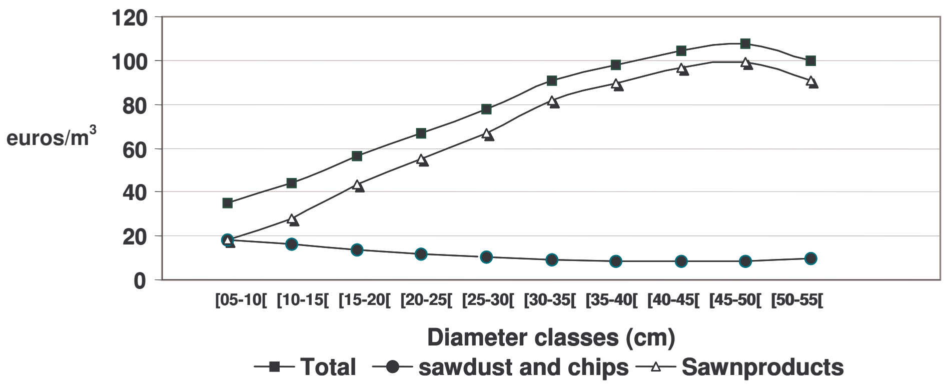


Figure 6 : Value of sawn products, sawdust and chips obtained per m^3 of raw material for different log diameter classes.

Figure 7 shows the yield of sawn timber products for logs in different positions in the stem, when quality grades are defined in the input data. Yield decreases from butt to top logs due to the diameter decrease and knot volume proportion increase. The study of the 3D reconstructed stem internal knot structure of the 20 trees from site 1 (Pinto *et al.,* 2000) has shown that the knot core increases with tree height, with the proportion of knots increasing significantly from butt to top logs.

In the case of S3 trees the yield of butt logs was similar to middle logs. For these trees, butt swell was very evident and taper values were high (Tab. 3). A sawing simulation done with the same input data but cross cutting the first log 1m from the butt to avoid butt swell, results in an average 8% increase in the sawing yields for butt logs.

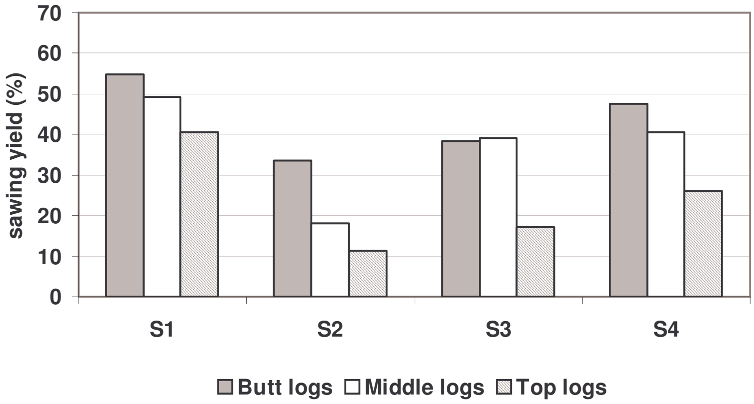


Figure 7 : Yield of sawn timber products with quality grade specification for butt, middle and top logs from the different sampled sites.

Figure 8 shows the grade distribution of the sawn boards when sawing simulations were executed for maximising value yield, considering the following relative selling prices of boards : 1st grade : 100 ; 2nd grade : 73 and 3 rd grade : 57.

The software searches a solution that maximizes the total value of the products taking into account each single knot inside the log and the rules for the grading of products (Tab. 4). The final sawing solution is very much depending on the prices of products defined by dimensions, lengths and grades. Overall, first grade boards were 79% of the total volume of boards when all the logs were sawn together. A higher proportion of 1st grade boards was obtained from logs from site S1 where 80% of the boards volume fell in the best grading class, while first grade boards corresponded to only 58% of the total boards volume from logs from the other sites. This large difference in the yields obtained for first quality boards between sites is a result from the fact that in site S1 butt logs have been pruned. This stresses the importance of pruning maritime pines at early stages because the tree has well branched first crown whorls and a weak natural pruning (Tavares, 1999).

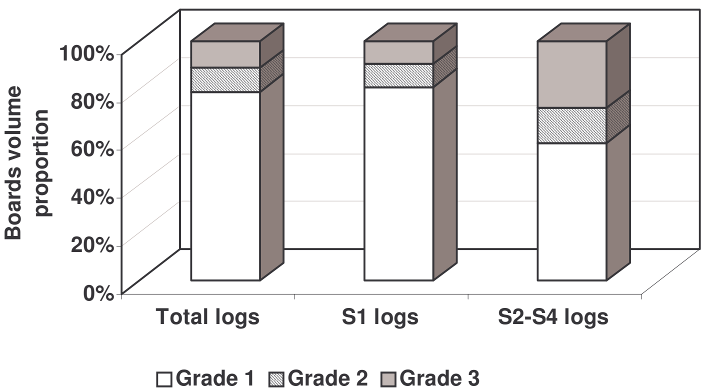


Figure 8 : Volume proportion of 25 mm boards by quality grades in value optimised sawing simulations for the total of the logs, for S1 logs, and for S2, S3 and S4 logs.

Influence of sawkerf

The influence of sawkerf on sawing yield was simulated by changing the sawkerf. Sawing yield is 55% when a theorical sawkerf is 0 mm. Yield drops to 46%, when a 6 mm sawkerf is used in sawing. By increasing sawkerf by 1 mm, the yield decreases in average by 3%, which means a loss of 4,5 €/m^3 raw material used. Figure 9 shows the variation in the sawing yield by changing the sawkerf for three different diameter classes. The influence in yield by the increase of sawkerf is higher for larger diameters.

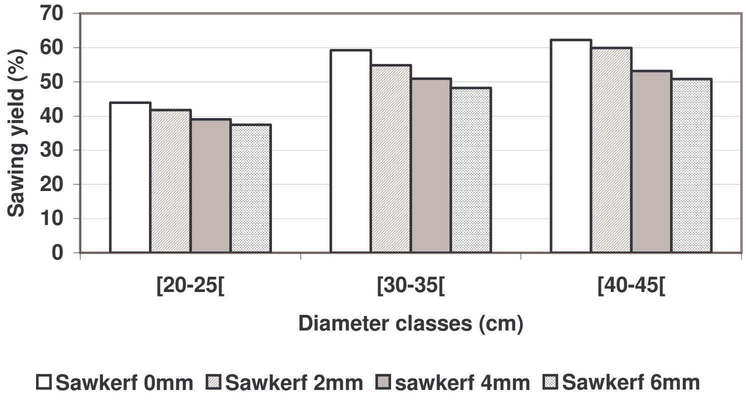


Figure 9 : Variation of yield of sawn timber products with the increase of sawkerf.

Comparison of simulation outputs with industrial yields

Comparison of simulated with industrial sawing yields was made using the results of Ferreira (2002) who measured yields of maritime pine logs in a Portuguese sawmill. In this study, the top diameters of logs sawn into lumber and boards ranged from 214 mm to 276 mm and their position in the tree was 1st, 2nd or 3rd. The average volume yield of sawn timber products calculated for these logs was 45.9 % (st. dev = 5.6 %).

From the 218 virtual logs used in the present simulation, 16 logs had the same top diameters and position in the tree and were used as the input raw-material for one sawing simulation. The average simulated sawing yield for these logs was 46.2 % (st. dev = 5.1 %) and the sawing pattern used in the simulation was similar to that used in the mill. The simulated sawing matches well the sawing in a real industrial environment which means that the software can be used to produce useful information for sawmills utilising Maritime pine wood raw material.

CONCLUSION

The WoodCIM® sawing simulation software has shown potential to optimise the operating instructions in the sawing process of Maritime pine and to clarify the influence of different raw material characteristics and production parameters on the recovery of sawn timber. Virtual sawing results were close to those realised in practice when similar situations were compared.

This study will contribute to increase the knowledge on the variations of Maritime pine sawing yield outputs with different factors and to connect these results with raw material main characteristics. The preliminary results presented in this paper indicate that there is a need to continue the studies to create new useful information to the industry, such as bucking instructions and limits of log classes based on the information regarding external shape and internal defects in order to increase value of the production. Further work will consist in adding new features into the sawing simulation, e.g. taking into account annual growth rings, resin pockets and heartwood content in the logs.

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