



# 3D OPTIMIZATION OF CUTTING PATTERNS FOR LOGS OF PINUS RADIATA D. DON WITH CYLINDRICAL DEFECTIVE CORE

Carlos Acevedo Correa, Mario Ramos Maldonado, Danny Monsalve Lozano,  
Cristhian Aguilera Carrasco

## ► To cite this version:

Carlos Acevedo Correa, Mario Ramos Maldonado, Danny Monsalve Lozano, Cristhian Aguilera Carrasco. 3D OPTIMIZATION OF CUTTING PATTERNS FOR LOGS OF PINUS RADIATA D. DON WITH CYLINDRICAL DEFECTIVE CORE . MOSIM 2014, 10ème Conférence Francophone de Modélisation, Optimisation et Simulation, Nov 2014, Nancy, France. hal-01166645

**HAL Id: hal-01166645**

**<https://hal.science/hal-01166645>**

Submitted on 23 Jun 2015

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

## 3D OPTIMIZATION OF CUTTING PATTERNS FOR LOGS OF *PINUS RADIATA* D. DON WITH CYLINDRICAL DEFECTIVE CORE

Carlos Acevedo C., Mario Ramos M., Danny Monsalve L., Cristhian Aguilera C.

University of Bío-Bío

Avenida Collao 1202 – Concepción – Chile

caceved@alumnos.ubiobio.cl, mramos@ubiobio.cl, danmonsa@alumnos.ubiobio.cl, cristhia@ubiobio.cl

**ABSTRACT:** The objective of this study was to find an efficient method to improve the work time and yield of volumetric use and utilities of the sawmills that process the pruned logs of *Pinus radiata*, linking the external information provided by an industrial scanner and the simulation of defective cylindrical core (DCC) in the constitution of a three-dimensional log, where the optimal cutting patterns were established by means of a dynamic programming algorithm. Sawing was simulated with a sample of 100 logs obtained randomly by an industrial scanning process. The results were compared with those obtained by a heuristic, perform by a company, based on practice. Dynamic programming algorithms reached a yield of the gross material of 64% and in relative terms a net utility average of 11 US\$/log is obtained.

**KEYWORDS:** Optimization, cutting pattern, sawmill, prune logs, *Pinus radiata*, 3D.

### 1 INTRODUCTION

In Chile, the species *Pinus radiata* dominates with 64% of the national area planted, so the presence in sawmills reaches 95% of total production in the country, (INFOR 2012a). Pruning, as silvicultural intervention pursues the develop of knots-free wood, resulting in truncation of the branches, reflected in an occlusion area between the DCC and the boundary with the clear wood, such region varies depending of the tree height and cutting technique used, (O'Hara 2007).

According to Lin *et al.* (2011), principal primary processing operations (debarking, sawing, resawing, edging and trimming) are complicated by the logs geometry and quality, the sawing method used and the mixture of the demanded products, thus Thomas (2008) points that the accurate information about the size, the shape and location of internal log defects it's the key to improve the value and quality of sawn wood. In this context, Rojas & Ortiz (2009) and Aguilera *et al.* (2002) reported methods to the identification of DCC through X-rays and CT respectively, although, away from the margins of productive time.

Mcphalen (1978) points that, in mathematical terms, determine optimal sawing patterns is a problem of Cutting and Stock (CSP) in two or more dimensions. As an example of the proposed models and techniques for solving problems in sawmilling industry, we found the optimal allocation of parts to logs. Gilmore & Gomory (1961 & 1963) report a knapsack integer linear programming algorithm, which do not throw good cutting patterns cause the impossibility to locate small rectangular elements. Faaland & Briggs (1984) evaluated the sequence of production dump and processing in sawmill, for which they made a dynamic model where decision criteria produced a short sequence of steps or subproblems to solve. Geerts (1984) reported a mathematical solution to a cutting problem of two-dimensions in an

irregular spot that could be extended to a third dimension. In its computational implementation, the algorithm, uses the commercial information of the wood orders required to improve the sawing patterns for one specific log with a defined DCC. Maness & Adams (1991) shows a linear programming model whose core is the bucking and the sawing politics to maximize profit according to distribution of the gross material input. The output of the product depends of the price-volume relation that simulate the curves of product demand. Reinders (1992), proposes an integral solution of the production chain in three levels : bucking, bases and tables. The determination of the optimal cut pattern, it's performed, through a knapsack problem of 2D. Todoroki & Rönnqvist (1999) raised, according to the principles of dynamic programming, two models of recurrence that maximize the value of production, based on scanning logs and maximizing the value of this, in terms of efficient allocation of the products taking the foresight to avoid possible defects presences in the log in regard to width and length. Novak (2007) as Mcphalen (1978), supports its formulation under two complementary modules. The first is responsible for generating the possible cutting patterns by diameter class through a recurrent formulation. The results form the initial set of solution in a column generation algorithm, that constitute the tool of the second solution module of the proposed model. Carnieri & Mendoza (2000) raised a fractional formulation based on the principles of Gilmore and Gomory (knapsack problem) and generated different validation scenarios, as demand flexibility and variation in time. Quintero & Rosso (2001) generated a diagrams cutting simulator based on the characteristics of the log (shape, defects, specie). They also raised a log stocktaking model and kinds of machinery used in the transformation process. Caballero *et al.* (2009) established a multi-agent model, in order to maximize profit and reduce production time in the efficient allocation of goods to logs. Maturana *et al.* (2010) evaluated the programming of the timber production from an

accurate model, compared to that achieved by the implementation of heuristics. Herrera & Leal (2012) propose a methodology for generating cutting patterns, minimizing waste levels, using a linear programming model that provides feasible cutting patterns for different diameter classes. Lin *et al.* (2010), Lin *et al.* (2011), Lin & Wang (2012) developed a dynamic programming algorithm based on Bhandarkar *et al.* (2008) to optimize a log of hardwood species reconstructed a three-dimensional model of internal defects developed by Thomas (2008).

The present study had the overall objective to develop an efficient method that allows time and performance increase volume use and usefulness of the sawmills that process logs-das pruning of *Pinus radiata*, through the 3D optimization of the log, considering the DCC.

## 2 MATERIALS & METHODS

In the sawmill, the log is moved by a conveyor chain, being longitudinally scanned by sensors (scanners), usually three. Each captures an arc of points of a semi-circumference of the log mantle, (Figure 1).

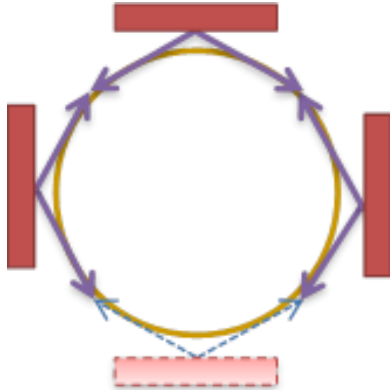


Figure 1: Disposition for industrial scanner.

Each arch is formed by about 90 points in two dimensions (2D), which are grouped into ranges or intervals, separately stored in a variable, within a class, to form cross sections that are spaced at 0.1 meters. Subsequently, the data is filtered to obtain a range of points to be a variable, which account with about 2500 points within a section. Consecutively treated with these points, the ellipse having major adjustment for all of these points is calculated, obtaining the model of the ellipse, which is adjusted to the actual points of measurement for the model called polar. Internally, there are three profiles of points: gross from the scanner, which make up the pattern and polar ellipse based on the ellipse, but fit the gross score of the log mantle.

The projection of points referenced in the average of the three axis: centroids of first and last sections of the log, allows projecting straight from the axle to the centroid, in the cartesian planes XZ and YZ, which determines magnitude and angle vector with respect to the axis X. Consecutively rotated vectors in space for the component in the Y axis. The above method, the sum of the magni-

tudes of each section is determined by storing the larger angle and the largest magnitude of this, for determining the maximum common area of all polar sections in order to analyze the variation of the log in the Z axis (Figure 2), and avoid the presence of pieces of wood with bark.

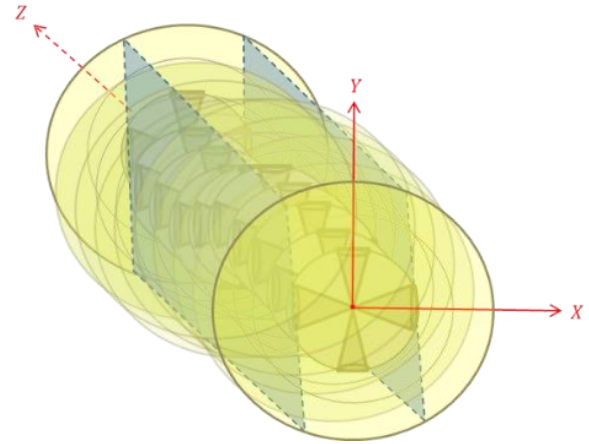


Figure 2: 3D log reconstruction.

### 2.1 Mathematical Model

Based on Bhandarkar *et al.* (2008), Lin *et al.* (2010), Lin *et al.* (2011) and Lin & Wang (2012), who has generated a mathematical model and algorithm for logs of broad-leaf species, where internal nodes, that forms a whorl, are predicted through a system developed by Thomas (2008), the model and algorithm that breaks the slice of the cross section of the log was established, intending to generate the pattern cut into quarters, pursuing to encapsulate the core base that contains the DCC, to ensure that the lateral areas of the log are maximized in its use, since this area has clear wood that has a higher price in the market, (Figure 3).

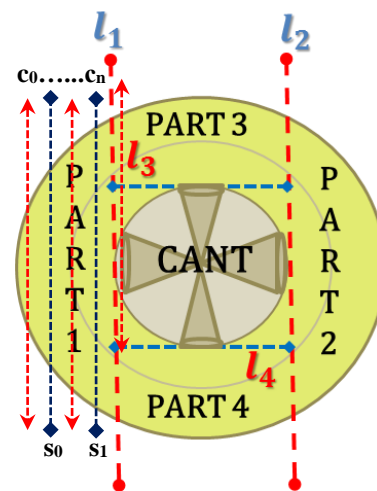


Figure 3: Cant Sawing

The mathematical model to maximize the production of sawed wood can be expressed by the following function objective (F):

$$F = [L_1^*, L_2^*(L_1^*), L_3^*(L_1^*, L_2^*), L_4^*(L_1^*, L_2^*, L_3^*), \\ S_1^*(L_1^*), S_2^*(L_1^*, L_2^*), S_3^*(L_1^*, L_2^*, L_3^*), \\ S_4^*(L_1^*, L_2^*, L_3^*, L_4^*)] \quad (1)$$

Where

$L_1, L_2, L_3, L_4$ :	Are the sawing plane of each part.
$S_1, S_2, S_3, S_4$ :	Are the sawing patterns of each part.
$V$ :	It is the value of the wood.
$*$ :	Indicates an optimum value.

The objective of this equation is to find the locations of  $L_1, L_2, L_3$  and  $L_4$  to maximize the total value of sawed wood. To generate the required sides, each part of the log is divided into  $n$  equidistant sawing planes, with a resolution of  $c$ . A sawing plan is denoted by  $L_1$  in the first portion.

Then  $c = \{1, 2, \dots, N\}$  is a finite set of all potential sawing planes, and  $S = \{s_0, s_1, \dots, s_n\}$  is a subset of  $c$  satisfying the following constraints:

$$(s_i - s_{i-1} - \left\lfloor \frac{K}{c} \right\rfloor) \times c \in T, \quad \forall \quad i \geq 1; i \leq N \quad (2)$$

$$s_0 = 1, s_N = N \quad (3)$$

Where:

$T = (T_1, T_2, \dots, T_m)$ :	Is a set of timber thickness (mm), $m$ is the total number of considered wood thicknesses.
$K$ :	It is the thickness of the cut slot, Kerf (mm).
$N = \frac{CR}{c}$ :	Is the total number of sawing planes in the sawing cut range. Therefore, the possible cutting planes are numbered as $1, 2, \dots, N$ . While, $CR$ is the cutting range (mm) between the first cutting plane and the central base.

A cutting pattern that satisfies equations (2) and (3) is considered as a possible solution to the log. The optimal cutting pattern is determined by the dynamic programming algorithm described by Bhandarkar *et al.* (2008), integrating the recursive equation of uniform sawing reported by Lin *et al.* (2011) and the recursive relation for edgings proposed by Lin & Wang (2012), which can be expressed as follows:

$$v^*(i+1, j+1) = \max_{r \in [0, l]} \left[ \max_{s \in [1, m]} \left[ \max_{t \in [1, n]} \left( v^* \left( i+1 - \frac{T_r}{c_1} - \left\lfloor \frac{K}{c_1} \right\rfloor, j+1 - \left\lfloor \frac{W_s}{c_2} \right\rfloor - \left\lfloor \frac{K}{c_2} \right\rfloor \right) + g \left( i+1 - \left\lfloor \frac{T_r}{c_1} \right\rfloor, i+1, j+1 - \left\lfloor \frac{W_s}{c_2} \right\rfloor, j+1, \right) \right) \right] \right] \quad (4)$$

Where:

$v^*$ :	It is the optimal value of the timber produced.
$T_r = \{L_1, L_2, \dots, L_l\}$ :	It is the set of demanded thicknesses of sawed wood.
$W_s = \{W_1, W_2, \dots, W_m\}$ :	The set of widths of the demanded sawer wood.
$c_1$ & $c_2$ :	Are the width and thickness ranges, respectively.
$K$ :	It is the cut slot of sawing (kerf)

However, to determine the optimal value of  $l_1$  and  $l_2$ ; and  $l_3$  and  $l_4$  is used a exhaustive search algorithm described by Bhandarkar *et al.* (2008).

## 2.2 Implementation & Validation

The computational implementation was done in computer language C#, using the editor and compiler *Visual Studio 2010 Professional* with *JoeScan* to capture images of the mantle of the log and *DirectX v.9* to graph cut patterns.

The statistical validation of the results was performed by means of two-sample t test compared to a heuristic developed by an industry of the region that arises conceptually as it shows next:

- Determine amount of curvature of the log.
- Determination of parameters to determine centering position.
- Position the maximum sweep of the log upwards.
- Find the greatest common area between the cross sections of the log.
- Build a rectangle with base A and higher B. (Figure 4)
- Building plan of cuts in zones: lateral and base central.

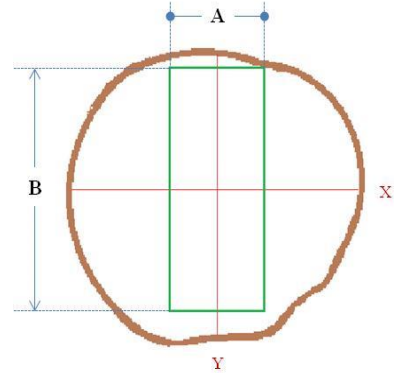


Figure 4: Parameters rectangle built by heuristic.

## 2.3 Definition of Parameters

According INFOR (2005), the use of the species *Pinus radiata*, depends on the height of the tree in which the log is removed, these being: roundwood debobinable, up

to 5 meters; wood sawlog, between 5 and 10 meters; roundwood pulpwood, between 10 and 15 meters and the remaining fuelwood.

Therefore, based on Karsulovic *et al.* (2005) and Toledo (2007), it was determined that for the case of the species, in question is considered in its harvest period, a diameter of DCC of 10 cm, a length of internode averaging 70 cm. with whorls of four knots centered pith simulated as truncated cones and oriented at  $24^\circ$  to the pith (Figure 5), which is complemented with the mantle of the log through the images provided by the industrial scanner.

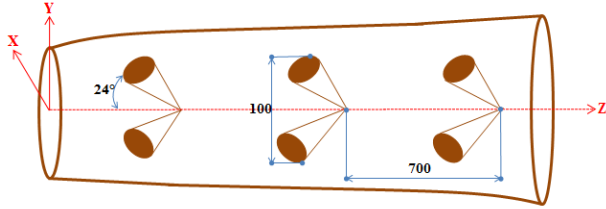


Figure 5: Parameters of log.

These are initial values, because: DCC diameter, internode length and width kerf are parameters that can be defined, in sawing conditions terms of the log and the machines involved in the sawing process.

Are utilize sawed wood for general use with the most demand in the country, according CORMA (2007), while the length correspond to the log process longitude. While, to evaluate the yield of the log using the following expression:

$$Yield(\%) = \frac{VST}{VL} \times 100$$

**VL:** Volume of the log, ( $m^3$ JAS).

**VST:** Volume of sawn timber, ( $m^3$ ).

Meanwhile, the determination of the volume of lumber is carried out considering the dimensions (thickness, width and length) and number of parts obtained from the log.

Moreover, to assess volume obtaining lumber free of knots, namely, the economic performance, trading prices, are referenced as published by INFOR (2012b), which reports in the last 17 years the wood clear intended export has reached an average price of 218,1 (US\$/ $m^3$ ), while the lumber with presence of knots are in the domestic market at an average price of 143,8 (US\$/ $m^3$ ), having a price reduction by 34% compared to wood distributed in foreign markets. The logs commercialized by ruma meter ( $1m \times 1m \times 2.44 m$ ) reach a value of US\$ 50, deducted the amount of 21 US\$/ $m^3$ .

The implemented dynamic programming algorithm statistically validated with a sample of 100 logs, comparing the yield of logs and net utility of lumber with that obtained by the heuristics developed by an industry of the region.

### 3 RESULTS & DISCUSSION

#### 3.1 Gross Material Yield

The behavior of the utilization of the gross material on the diameter of the log, differentiated optimization method used is shown in Figure 6.

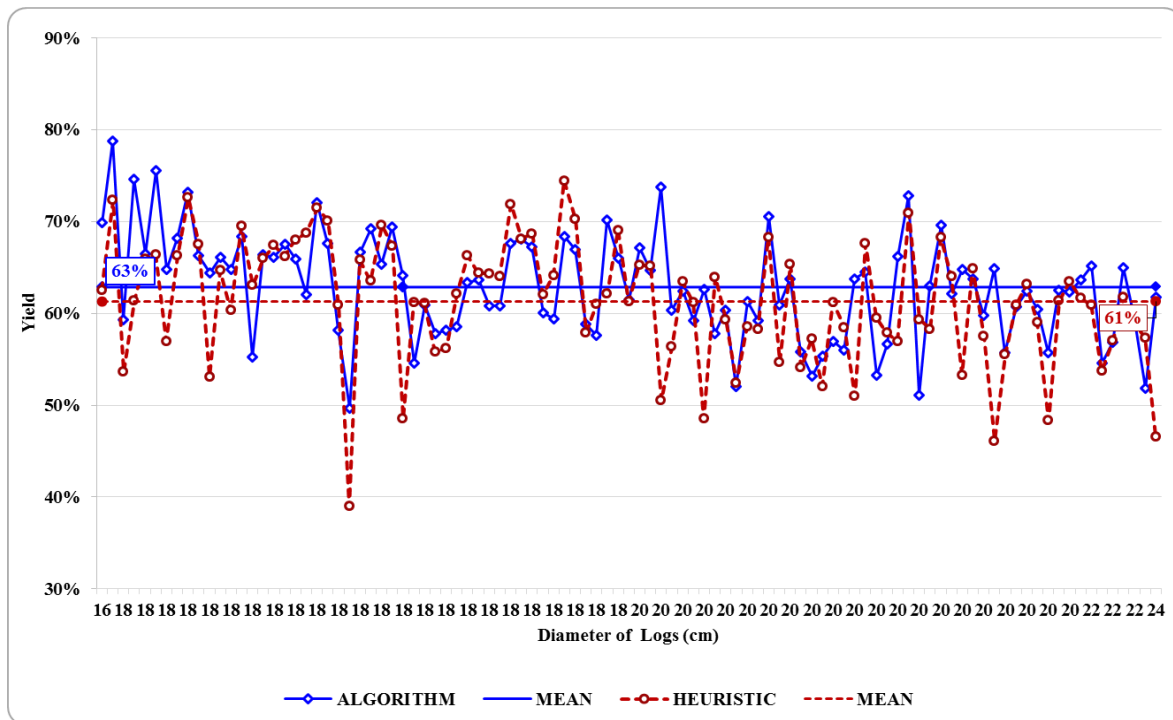


Figure 6: Comparison of the yield of gross material.

In regard to the yield of the gross material, it is possible to state that there was an average percentage difference of 2% in favor of the dynamic programming algorithm (DPA) over comparative heuristics. In the first method used a range of 19% yield with an average of 63% utilization of the logs is reached, while the second method reached a range of 35% yield with an average of 61% utilization of logs. In comparison, the utilization recorded by DPA has less fluctuation, reflected in lower utilization interval of logs with respect to heuristic confronted, in turn, is also interesting to note the stability

that has tested the algorithm in the distribution of the diameters of logs used, point it is not possible to highlight the method collated.

### 3.2 Net Utility

Figure 7 shows the behavior of the net utility of lumber according to the diameter of the log, differentiated by optimization method used.

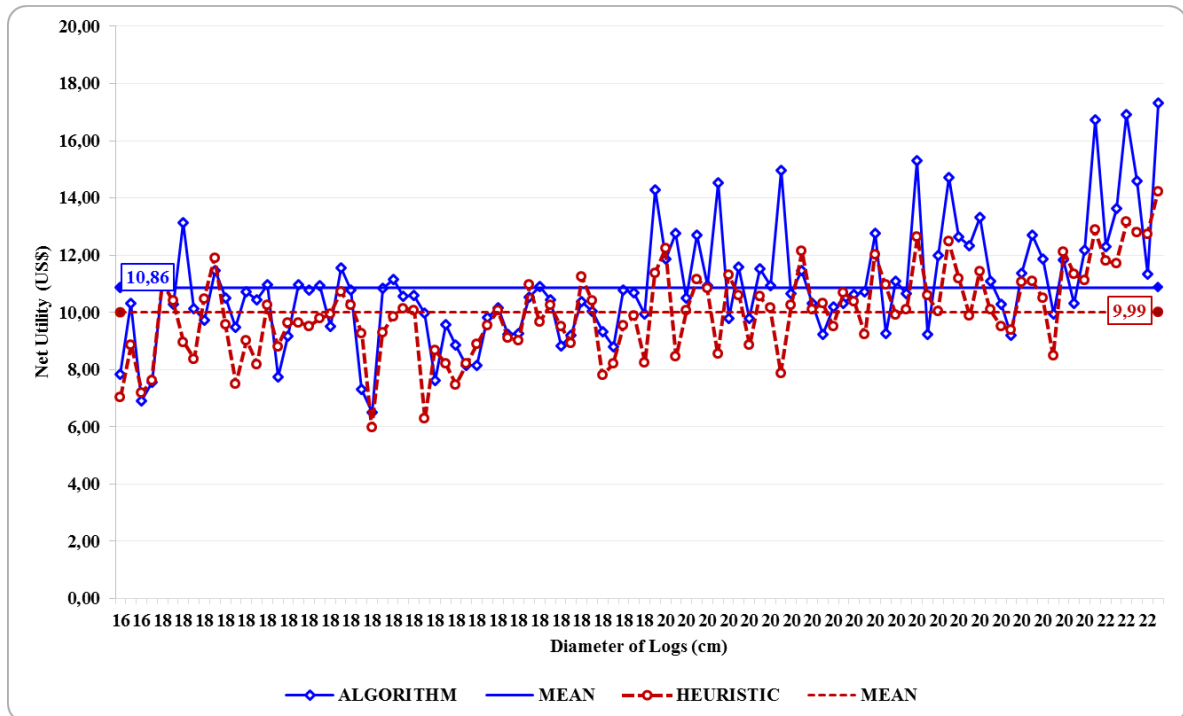


Figure 7: Comparison of net utility of lumber.

In terms of net utility from the timber, PDA prevails over the comparative method. In the first case an average of US\$ 10,86 is achieved with a standard deviation of US\$ 2,03 in contrast to the US\$ 9,99 average and standard deviation of US\$ 1,53 that records the heuristic. PDA focuses on a global optimization (volume and value) of the log, privileging the economic utility of the timber, while the heuristic comparison only optimizes the use of the log, which in some cases yields better use of the method of comparison.

Meanwhile, with a confidence interval of 95%, it can be stated that there is a statistical difference between the two optimization methods in terms of the yield of the log and net utility of lumber, being observed that economic statistical comparison is significantly for the dynamic programming algorithm ( $p\text{-value} = 0.00037$ ).

The proposed optimization method lacks consideration of contingencies that arise only in the daily operation of a sawmill, since only have run simulations sawmilling process, unable to ascertain the possible impact of using

different methods of sawing and/or redistribution of machines in the production line.

Using parameters collected in the literature review to determine the size and behavior of the DCC in the log, confers instability to the proposed optimization cuts logs method, since the biological origin of the tree gives a low uniformity parameters of logs, however, a promising progress in the techniques of non-destructive detection on the internal condition of the logs, contribute to an accurate three-dimensional reconstruction of the log in order to establish with certainty the regions of clear lumber.

## 4 CONCLUSIONS

The possibility of finding an efficient optimization method sawing time and performance that would increase the volumetric utilization of the gross material, positive impact on the profits of the sawmills that process logs pruned *Pinus radiata* was investigated. The dynamic programming algorithm used, is the most suitable, as it seeks the best solution based on recursive



relationship described, involving behavior DCC, cross sections and over logs. The increase in profits was achieved because the model studied, favors optimization of regions free of defects in logs, sawn obtaining clear higher-value wood pieces that have knots, still, possible to assert that the scheduling algorithm abundantly dynamic achieves significant increase utility sawmill, recording a significant increase in the use of logs.

The dynamic programming algorithm with a confidence interval of 95% shows a statistically significant difference with respect to heuristics developed by the company local in harnessing the gross material and net utility of lumber, reflected in obtaining a greater volume of lumber free of defects.

## ACKNOWLEDGMENTS

We thank the Department of Postgraduate, University of Bío-Bío by Research Scholarship 2013, as the Project 3D Scanner Teknip-UBB.

## REFERENCES

- Aguilera, C., M. Ramos, D. Salinas, 2002. Visualización interna de nudos en rollizos de madera de *Pinus Radiata* D. Don utilizando Rayos-X. *Maderas. Ciencia y Tecnología*, 4(2), p. 198 – 200.
- Bhandarkar, S., X. Luo, R. Daniels, and E. Tollner, 2008. Automated planning and optimization of lumber production using machine vision and computer tomography. *IEEE Transactions on Automation Science and Engineering*, 5(4), p. 677-695.
- Caballero, R., T. Gómez, J. Molina, O. Fosado, M. León, and M. Garofal, 2009. Sawing planning using a multicriteria approach. *Journal of Industrial and Management Optimization*, 5(2), p. 308 – 317.
- Carnieri, C., and G. Mendoza, 2000. A Fractional algorithm for optimal cutting of lumber into dimension parts. *Annals of Operations Research*, 95, p. 83 – 92.
- CORMA (Corporación Chilena de la Madera), 2007. *Manual de Construcción de Viviendas en Madera*, Centro de Transferencia Tecnológica de la Madera. Chile.
- Faaland, B., and D. Briggs, 1984. Log bucking lumber manufacturing using dynamic programming. *Management Science*, 30 (2), p. 245 – 257.
- Geerts, J., 1984. Mathematical solution for optimising the sawing pattern of a log given its dimensions and its defect core. *New Zealand Journal of Forestry Science*, 14(1), p. 124 – 134.
- Gilmore, P., and R. Gomory, 1961. A linear programming approach to the cutting stock problem. *Operations Research*, 9, p. 849-859.
- Gilmore, P., and R. Gomory, 1963. A linear programming approach to the cutting stock problem, Part II. *Operations Research*, 11, p. 863 – 888.
- Herrera, J., and R. Leal, 2012. Generación de patrones de corte a partir de la programación matemática para la planificación táctica-operativa de aserríos madereros. *Colombia Forestal*, 15(2), p. 227 – 245.
- INFOR (Instituto Forestal), 2005. *El sector forestal chileno en una mirada*. Ministerio de Agricultura, Gobierno de Chile.
- INFOR (Instituto Forestal), 2012a. *Anuario Forestal*. Ministerio de Agricultura, Gobierno de Chile. Boletín Estadístico N° 136
- INFOR (Instituto Forestal), 2012b. *La industria del aserrío*. Ministerio de Agricultura, Gobierno de Chile. Boletín Estadístico N° 137.
- Karsulovic, J., M. Dinator, J. Morales, V. Gaete, and A. Barrios, 2005. Determinación del diámetro del cilindro central defectuoso en trozas podadas de pino radiata (*Pinus radiata*) mediante atenuación de radiación gamma. *Bosque*, 26(1), p. 109 – 122.
- Lin, W., and J. Wang, 2012. An integrated 3D log processing optimization system for hardwood sawmills in central Appalachia, USA. *Computers and Electronics in Agriculture*, 82, p. 61 – 74.
- Lin, W., J. Wang, and E. Thomas, 2010. A 3D optimal sawing system for small sawmills in central Appalachia. Proceedings of the 17th Central Hardwood Forest Conference. General Technical Report NRS-P-78. USDA Forest Service, Northern Research Station, Newtown Square, p. 67–76.
- Lin, W., J. Wang, and E. Thomas, 2011. A 3D optimal sawing system for small sawmills in central Appalachia, US. *Wood and Fiber Science*, 43 (4), p. 379 – 392.
- Maness, T., and D. Adams, 1991. The combined optimization of log bucking and sawing strategies. *Wood and Fiber*, 23 (2), p. 296 – 314.
- Maturana, S., E. Pizani, J. Vera, 2010. Scheduling production for a sawmill: A comparison of a mathematical model versus a heuristic. *Computers & Industrial Engineering* 59(4): 667 – 674.
- Mcphalen, J. 1978. *A method of evaluating bucking and sawing strategies for sawlogs*. Master Thesis, University of British Columbia, Canada.

- Novak, R., 2007. *Um sistema de otimização aplicada ao desdobro de madeira*. Tesis de Maestría, Universidade Federal do Paraná, Brazil.
- O'hara, K., 2007. Pruning wounds and occlusion: a long-standing conundrum in forestry. *Journal of Forestry*, 105 (3), p. 131 – 138
- Quintero, M., and F. Rosso, 2001. Propuesta de un simulador de aserraderos para la industria forestal Venezolana. *Revista Forestal de Venezuela*, 45(1), p. 95 – 101.
- Reinders, M., 1992. Cutting stock optimization and integral production planning for centralized wood processing. *Mathematical and Computer Modelling*, 16(1), p. 37 – 55.
- Rojas, G., and O. Ortiz, 2009. Identificación del cilindro nudoso en imágenes TC de trozas podadas de Pinus Radiata utilizando el clasificador de máxima verosimilitud. *Maderas. Ciencia y Tecnología*, 11(2), p. 117 – 127.
- Thomas, E., 2008. Predicting internal Yellow-Poplar log defect features using surface indicators. *Wood and Fiber Science*, 40 (1), p. 14 – 22.
- Todoroki, L. and E. Rönnqvist, 1999. Combined primary and secondary log breakdown optimization. *Journal of the Operational Research Society*, 50, p. 219-229
- Toledo, M. 2007. *Comportamiento del largo de internudos en plantaciones de Pinus radiata D. Don en sitios ex agrícolas de la VII región*. Trabajo para obtener título de Ingeniero Forestal. Valdivia – Chile. Facultad de Ciencias Forestales, Universidad Austral, Chile.