Applying Optimum Bucking Method in Producing Taurus Fir (*Abies cilicica*) Logs in Mediterranean Region of Turkey

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Abstract

In producing forest products, it is essential to buck trees into high quality logs with maximum value. Performing bucking in an optimum way is an important factor to increase the value in timber production. Computer-assisted methods using modern optimization techniques (i.e. network analysis, dynamic programming, and heuristic techniques) can provide the forest engineers with an optimum solution for bucking problems by quickly evaluating large number of bucking combinations for a single tree. In Turkey, bucking is generally performed based on loggers' experiences without any scientific approach. In this study, it was aimed to develop a stem-level optimum bucking algorithm that determines the optimum bucking pattern with maximum total stem value. The algorithm was implemented during a selective cutting of Taurus Fir (*Abies cilicica*) stands in the Baskonus Research and Application Forest of Kahramanmaras Sutcu Imam University (KSU), located in the city of Kahramanmaras in eastern Mediterranean region of Turkey. Dynamic programming (DP) method was used to develop the algorithm written with Microsoft Visual Basic (VB) Version 6.3 programming language. The results from the application indicated that using optimum bucking method increased the potential gross value and volume of the harvested trees by 9.31% and 4.18%, respectively, comparing with the traditional bucking method.

Key words: Optimum bucking, Logging, Optimization, VBA, Taurus Fir

Introduction

Increasing public demand due to high population growth rate and escalating consumer pressures on natural resources have required efficient, effective, and sustainable management of forest resources, which have been diminished due to irresponsible and excessive usage. In order to satisfy the demands of today's and future generations, the forests, as one of the renewable natural resources, should be managed by modern methods that ensure sustainable and optimum productivity.

In forest harvesting operations, once a tree is felled, limbed, and barked and stem deformations are removed, the process of dividing a tree into shorter logs is called bucking. Bucking a tree into the sections that maximize the total value is called the optimum bucking method (Sessions 1988). This method may increase the value of trees up to 20 % when accurate tree quality information is provided (Faaland and Briggs 1984, Olsen et al. 1991).

Large number of bucking combinations can be generated for a single tree. To determine the optimum combination, computer-assisted methods are required for quick evaluation of these combinations. Such a problem with many solutions can be solved using modern optimization methods that systematically search for the best solution. These methods may include network analysis, linear programming (LP), dynamic programming (DP), and heuristic techniques (Laroze and Greber 1997).

The optimum bucking problems can be categorized into three levels (Laroze 1999); (1) Stem-level problems to determine the optimum bucking for each stem in a way that maximizes the total stem value; (2) Stand-level problems to determine the best possible bucking result with maximum aggregate production value; and (3) Forest-level problems to maximize the global profit considering demand constraints, merchandising restrictions, and forest-estate. Network analysis techniques (Sessions1988) and DP (Nasberg 1985) have been effectively used to solve stem-level optimum bucking problems. Sessions et al. (1988a) developed a well-known optimum bucking program, BUCK, with a network analysis technique. The field studies indicated that BUCK was able to increase the timber volume and timber value by up to 14% and 22%, respectively (Sessions et al. 1989a, Garland et al. 1989). In a more recent study, Wang et al. (2004) implemented a stem-level optimum bucking problem by using network analysis, which resulted in approximately 14% increase in the gross log value.

At stand-level, optimum bucking problems have been generally formulated as two-level optimization problems utilizing both LP and DP (Sessions et al. 1989b, Laroze and Greber 1997). The optimization procedures involving heuristic techniques such as Tabu Search (Laroze 1999) and Genetic Algorithm (Kivinen 2004) have been used to solve forest-level bucking problems. Uusitalo (2007) developed a Genetic Algorithm based method to integrate transportation cost and product values into forest-level optimum bucking problem.

In a study conducted by Puumalainen (1998), a DP approach was used to apply optimum bucking method and sensitivity analysis in evaluating the effects of various log dimensions on produced yield. The results from this study indicated that log length was the most effective dimensional criteria on the yield. Besides, the timber volumes tend to vary between the stands of a region and within the stand. Gobakken (2000) conducted a study where a DP was developed to analyze tree values and cross-cutting patterns in optimal log bucking application. The study was applied on Norway spruce (*Picea abies* (L.) Karst.) stems located in three different regions of Norway. It was reported that increasing the number of log length alternatives increased the total value of the harvested sample trees. It was also indicated that taper equations tend to overestimate the total tree values. Uusitalo and Isotalo (2005) conducted an optimum bucking related study applied on Scots pine (*Pinus sylvestris* L.) stems from south-western Finland. They mainly analyzed the effects of knot characteristics on log quality. It was found that dead knots were the most important characteristic that affects quality grading in optimum bucking procedures.

In Turkey, optimum bucking method has not been implemented in forest operations. The bucking operation is mostly done depending on loggers' experiences without any scientific approach. However, it is highly anticipated that implementing optimum bucking method by systematically searching for the best result and by considering market demand can increase the net worth of timber production in Turkey.

In this study, stem-level optimum bucking algorithm was developed to determine the optimum bucking pattern that maximizes the value of each stem. The algorithm was written with Microsoft Visual Basic (VB) Version 6.3 programming language by using dynamic programming (DP) method (Sessions et al. 1988b). The algorithm was then applied to a bucking operation taken place in a selective cutting of Taurus Fir (*Abies cilicica*) stands in the Baskonus Research and Application Forest of KSU in eastern Mediterranean region of Turkey. The capabilities of optimum bucking method were then evaluated by comparing with the traditional bucking method.

Materials and methods

Optimum Bucking Method

In the optimum bucking method, each log is assessed mainly depending on log grades, log sizes (i.e. diameter and length), and mill delivered prices. The log grade is determined based on surface characteristics such as shape, knot size and density, and cracks, bending, and twisting on the logs (Olsen et al. 1997). Since these factors may change by tree species, the look-up tables for log grades should be made available for the commercial tree species.

In order to increase the performance of the optimum bucking method, accurate and current information should be collected about the market demand and market prices for each log grade with various diameters and lengths (Sessions et al. 1988a). The length and diameter classes used for coniferous trees in Turkey are listed in Table 1 (Kalıpsız 1999). If there is a transition from one grade to another grade along a log, the log grade at the small-diameter-end is generally considered in determining the grade of the log. The mill delivered prices that local log buyers pay for logs of various diameters, lengths, and grades should be also introduced to the optimum bucking method.

Table 1. The ranges of the length and diameter classes for the coniferous trees

Length Classes	Length (m)	Diameter Classes	Middle Diameter (cm)
Short (S)	1.5-2.5	Small (SD)	19-29
Normal (N)	3.0-5.0	Medium (MD)	30-39
Long (L)	5.5-8.0	Large (LD)	40-49
Very Long (VL)	? 8.5	Very Large (VLD)	? 50

There are a number of mathematical optimization methods to be used in systematically searching for the optimum bucking solutions. In this study, dynamic programming method with a node-labeling technique (Sessions et al. 1988b) was used to develop stem-level optimum bucking algorithm. In this algorithm, the tree is represented as a network of arcs where possible bucking points along the tree are considered as "nodes" and each "arc" between nodes is considered as the length of a possible log (Figure 1). The value of the arc represents the value received from the log that would be cut from the tree (Sessions 1988). To produce the highest total value from the whole tree, the "path" of arcs that yields maximum value is identified by the algorithm among a large number of alternative paths. To determine feasible alternatives, various decision variables such as minimum and maximum acceptable log lengths, minimum acceptable log diameter at the mid point of a log, and permissible defects should be considered in optimum bucking algorithm. In this study, since logging cost, transportation cost, and stumpage payments were not considered in the algorithm, each arc represents the log value. The log value was estimated based on log volume and mill delivered prices. The log volume was computed by using Huber's formula, which is the function of sectional area at the mid point of a log and log length (Carus 2002).

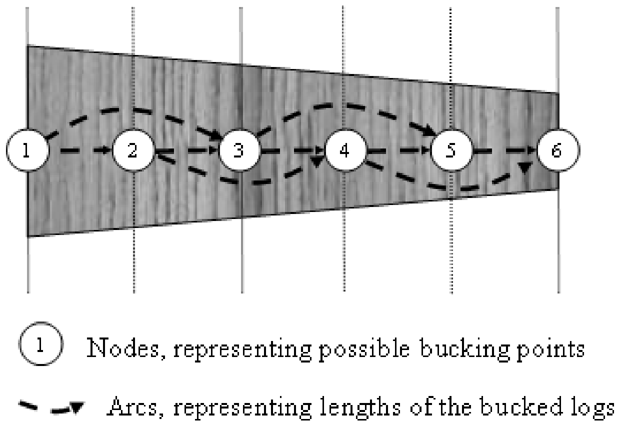

Figure 1. Network representation of a sample tree indicating possible nodes and arcs

Due to the specialized structure of the tree bucking problem, i.e., one state, and *n* stages, the problem can be solved in a simple way. The network consists of *n* nodes defining the *n*-1 bucking decisions. Logs are defined by their beginning and ending nodes. The optimal bucking solution is then found by finding the highest value path from node 1 at the base of the tree to node *n* at the top of the tree. This solution requires exactly *N* comparisons where *N* equals the number of possible logs segments including "waste" logs created by cutting out defects or tree breaks. The main steps of the optimal cutting algorithm are as follows:

Step 1. Label all possible bucking cuts from the base to the top of the tree,
Step 2. Define all feasible logs by their beginning and ending nodes (Begnode(i), Endnode(i)) and assign Value(i) to each log based on Begnode(i), Endnode(i).
Step 3. Sort the N logs by their beginning node
Step 4. Initialize Bestvalue(i), the highest value at each node i = 0
Step 5. For i = 1 to
If Bestvalue (Begnode(i)) + Value(i) > Best value (Endnode(i)) Then
Bestvalue(Endnode(i) = Bestvalue (Begnode(i))+ Value(i)
Prednode(Endnode(i)) = Begnode(i)
End If
Next i
Step 6. Use predecessor nodes from node n to node 1 to identify the optimal log mix

In statistical analysis, SPSS® 15.0 statistic software was used to investigate whether there is a significant difference for values and volumes of the set of harvested trees between traditional bucking method and optimum bucking method. The breast height diameters were regrouped into three classes (small < 40 cm; medium = 40-50 cm; and large > 50 cm) to investigate the effects of different diameter classes on value and volume gain of bucked logs due to using optimum bucking methods. The average lengths of bucked logs for harvested trees were also regrouped into three classes (short < 3.0 m; medium = 3.0-3.5 m; and long > 3.5 m) to investigate whether value and volume gain of bucked logs were significantly effected by different log classes.

Bucking Operation

The optimum bucking application was performed during a selective cutting of Taurus Fir (*Abies cilicica*) stands in the Baskonus Research and Application Forest of KSU, located in eastern Mediterranean city of Kahramanmaras in Turkey (Figure 2). The research forest is about 458 ha in which 374.5 ha is covered with forest. The dominant tree species in the forest are *Pinus brutia, Pinus nigra, Cedrus libani,* and *Abies cilicica*. The average ground slope and ground elevation are 73% and 1,165 m, respectively. To approximate a normal distribution, over thirty (i.e. 32) Taurus Fir trees were randomly selected from the felled trees for application of the optimum bucking method (Yenilmez 2010). The average breast height diameter and height of the sample trees were 42.81 cm and 16.00 m, respectively. The size (i.e. length, diameter) and log grades of the sample trees were recorded to run optimum bucking method for each tree. Then, the trees were bucked by using traditional bucking method based on loggers' experiences.

In this study, the logs extracted by the Baskonus Forest Enterprise were hauled to Tekerek Warehouse located in the city of Kahramanmaras and sold through

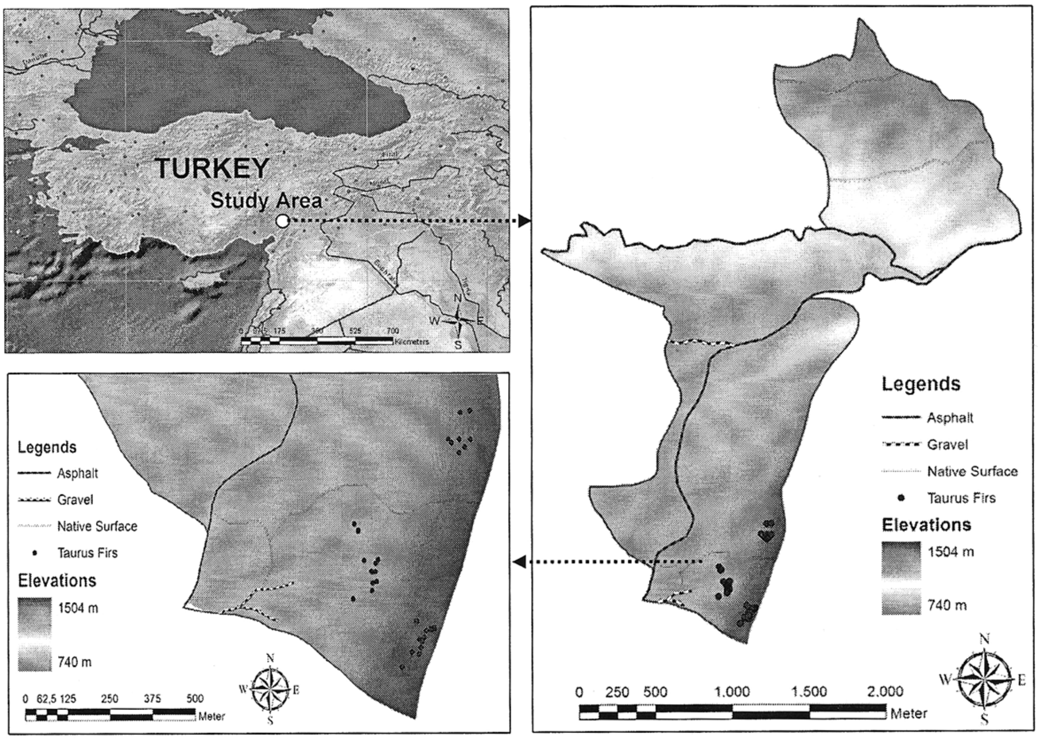

Figure 2. Baskonus Research and Application Forest and distribution of sample trees

public auctions. Therefore, the average log price for each log grade with various length-diameter classes was obtained from the Baskonus Forest Enterprise based on the most recent auction (Table 2). The maximum acceptable log length that can be produced was not more than 4 meters due to limiting capabilities of using traditional logging methods in the region. The minimum acceptable log length and minimum acceptable log diameter at the mid point of a log were 2 m and 19 cm, respectively.

Table 2. Log prices for Taurus firs with various length and diameter classes

Length - Diameter Classes	Log Prices (EUR/m^3)		
	I. Grade	II. Grade	III. Grade
S-SD	72,00	62,40	55,20
S-MD	74,40	64,80	57,60
S-LD	79,20	67,20	60,00
S-VLD	81,60	69,60	62,40
N-SD	76,80	67,20	60,00
N-MD	79,20	69,60	62,40
N-LD	84,00	72,00	64,80
N-VLD	86,40	74,40	67,20
L-SD	79,20	69,60	62,40
L-MD	84,00	72,00	64,80
L-LD	88,80	74,40	67,20
L-VLD	93,60	76,80	69,60

Results

In almost the entire harvested tree, bucking patterns generated by optimum bucking method was different from the bucking patterns generated by the traditional bucking method (Table 3). However, the statistical results indicated that the difference for values of bucked trees between traditional bucking and optimum bucking methods was not significant ($p = 0.357$). The general statistical results were listed in Table 4. The potential gross values of bucked trees by using the traditional bucking method and optimum bucking method were 5098.72 TRY and 5573.65 TRY, respectively. Thus, using optimum bucking method increased the potential gross value of the harvested trees by 9.31%, comparing with the traditional bucking method.

The results also indicated that there was no significant difference for volume yield of bucked trees between two bucking methods ($p = 0.657$). The potential gross volume yield of bucked trees by using traditional bucking method and optimum bucking method were 37.09 m^3 and 38.64 m^3, respectively. Thus, the potential gross volume of the harvested trees using optimum bucking method was 4.18% more than that of using the traditional bucking method.

The effects of different breast height diameter classes (small, medium, and large) on value and volume gain of harvested tress due to using optimum bucking method were also investigated (Table 5). Sta-

Table 3. The bucking patterns generated by the traditional and optimum bucking methods

Tree No	Bucking Patterns: Traditional Method	Bucking Patterns: Optimum Bucking Method
1	15-13-11-9-7-5-3-1	15-12-9-5-1
2	11-7-5-3-1	11-8-4-1
3	11-9-7-5-3-1	11-9-5-1
4	13-11-9-7-5-3-1	13-11-8-5-1
5	13-11-9-7-5-3-1	13-10-8-5-1
6	13-11-9-7-5-3-1	13-10-7-5-1
7	15-13-11-9-7-5-3-1	15-11-9-5-1
8	9-7-5-3-1	9--5-1
9	13-11-9-7-5-3-1	13-11-7-5-1
10	11-9-7-5-3-1	11-9-5-1
11	13-11-9-7-5-3-1	13-11-7-5-1
12	13-11-9-7-5-3-1	13-9-5-1
13	12-8-5-3-1	12-8-4-1
14	16-14-12-9-6-3-1	16-12-10-7-5-1
15	16-13-9-5-1	16-13-9-5-1
16	13-9-5-1	13-9-6-3-1
17	14-11-8-5-3-1	14-11-8-5-1
18	14-12-9-6-3-1	14-12-9-5-1
19	14-12-9-6-3-1	14-11-8-5-1
20	14-11-7-3-1	14-11-7-5-1
21	17-15-13-10-7-5-3-1	17-13-9-5-1
22	15-13-10-7-5-3-1	15-13-10-7-5-1
23	20- 18-16-13-10-7-5-3-1	20-16-13-10-7-5-1
24	13-11-9-6-3-1	13-9-5-1
25	17-15-13-11-9-7-5-3-1	17-15-11-9-5-1
26	15-13-11-9-6-3-1	15-13-9-6-3-1
27	20-18-15-13-9-6-3-1	20-17-14-10-8-5-1
28	14-12-9-6-3-1	14-12-9-7-4-1
29	13-11-9-5-3-1	13-9-5-1
30	18-16-14-12-9-6-3-1	18-16-12-9-5-1
31	16-14-11-9-6-3-1	16-14-12-8-5-1
32	13-11-9-7-5-3-1	13-9-5-1

Table 4. Statistical summary table for value (EUR) and volume (m^3) of harvested tress by two bucking methods

	Bucking Method	N	Mean	Minimum	Maximum
Tree Value	Optimum	32	83.61	30.33	171.35
	Traditional	32	76.48	26.55	152.05
Tree Volume	Optimum	32	1.21	0.46	2.41
	Traditional	32	1.16	0.43	2.30

tistical analysis indicated that value gain of harvested trees significantly changed with diameter classes ($p = 0.003$). The maximum average value gain was for large diameter class (16.94 %), followed by medium (8.05 %), and small diameter (7.64 %) classes. There was also a significant difference on volume gain of harvested tress with different diameter classes ($p = 0.023$). The volume gain varied increasingly from small diameter class (3.16 %) to medium diameter (3.65 %) and large diameter (7.38 %) classes.

Table 5. Statistical summary table for value and volume gain of harvested tress by using optimum bucking method with respect to diameter classes

	Diameter Classes	N	Mean	Minimum	Maximum
Tree Value (%)	Small	9	7.64	0.02	14.23
	Medium	18	8.05	0.00	17.48
	Large	5	16.94	12.69	20.77
Tree Volume (%)	Small	9	3.16	0.00	6.98
	Medium	18	3.65	0.00	11.46
	Large	5	7.38	4.78	9.35

The results indicated that there was a significant difference for the average lengths of bucked logs between two bucking methods ($p < 0.005$). The overall average length of bucked logs of harvested trees bucked by traditional bucking method and optimum bucking method were 2.40 m and 3.32 m, respectively. The effects of different log lengths classes (short, medium, and long) on value and volume gain of harvested tress due to using optimum bucking method were not statistically significant ($p = 0.144$ and $p = 0.695$, respectively). However, average value gain of harvested trees for long logs (11.25 %) was considerably greater than that of harvested trees for medium and short logs (Table 6). The average volume gain (4.32 %) for medium logs was slightly greater than that of long logs.

Table 6. Statistical summary table for value and volume gain of harvested tress by using optimum bucking method with respect to log length classes

	Log Length Classes	N	Mean	Minimum	Maximum
Tree Value (%)	Short	3	3.73	0.02	7.86
	Medium	20	9.30	0.26	17.48
	Long	9	11.25	0.00	20.77
Tree Volume (%)	Short	3	2.68	0.00	6.50
	Medium	20	4.32	0.00	11.46
	Long	9	4.05	0.00	7.88

Discussion and conclusions

The optimum bucking patterns suggested by the optimum bucking method were different than the bucking patterns generated by the traditional bucking method, except only one sample tree. According to Wang et al. (2004), the loggers applying traditional bucking method may reach the optimum bucking pattern in a case where the bucking operation is performed by experienced loggers and harvested trees form straight stems with less number of defects.

Even though there was no significant difference for value and volume of bucked trees between traditional and optimum bucking methods, optimum bucking method resulted in 9.31% and 4.18% increase in the potential gross log value and volume. To investigate the effects of tree diameter and log size on value and volume gain of bucked logs, the breast height diameters and log lengths were both regrouped into three classes. The value and volume gain of the harvested trees did tend to increase from small diameter trees to large diameter tress. Figure 3 indicates the distribution of the sample trees according to diameter classes. It was found that 56% of the sample trees fall into medium diameter class, while 28% and 16% of the trees were in small and large diameter classes, respectively.

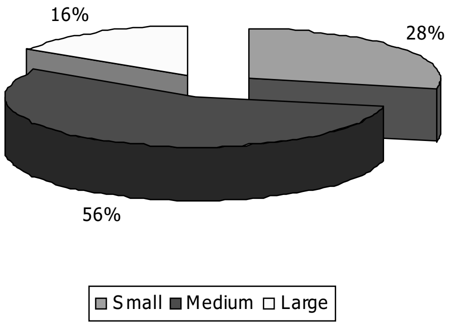

Figure 3. The distribution of the sample trees according to diameter classes

Similarly, the value and volume gain increases as the length of the bucked logs increases which proved that optimum bucking method provides better results for large size logs (Wang et al. 2004). Figure 4 indicates the distribution of the sample trees according to log length classes. It was found that 63% of the sample trees were in medium log length class, while 28% and 9% of the trees fell into long and short log length classes, respectively.

Maximizing tree value by implementing optimum bucking method is a rather complex problem that essentially requires correct bucking strategies considering log grades, log length, log diameter, and mill delivered price. Besides, appropriate logging methods should be available to extract various sizes of logs suggested by the optimum bucking method. In forest operations, traditional logging methods are not capable of transporting large size logs in Turkey due to lack of facilitating mechanized harvesting techniques. To increase value and volume yield of the harvested trees, the proportion of using mechanized logging methods in forest operation should increase so that longer log lengths with larger diameter can be produced, if suggested by optimum bucking method.

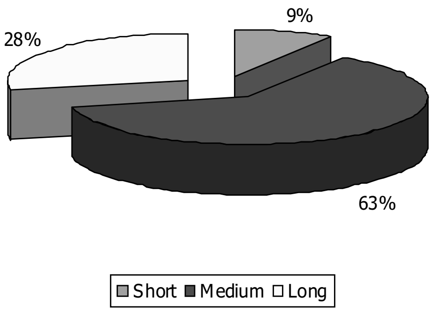

Figure 4. The distribution of the sample trees according to log length classes

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ВНЕДРЕНИЕ В ПРОИЗВОДСТВО ОПТИМАЛЬНОГО МЕТОДА РАССЕЧЕНИЯ НА БРЕВНА ПИХТЫ КИЛИКИЙСКОЙ (*ABIES CILICICA*) В СРЕДИЗЕМНОМОРСКОМ РЕГИОНЕ ТУРЦИИ

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Резюме

Быстрый рост населения и давление со стороны потребителей увеличило общественный спрос на лесоматериалы. Это обстоятельство инициировало поиск более эффективных и продуктивных методов по управлению уменьшающихся лесных ресурсов. В производстве бревна, являющемся одним из наиболее важных лесоматериалов, в первую очередь спиливаются деревья, обрубаются ветки, очищается кора, и удаляются все недостатки, имеющиеся на стволе. После этого процесса, деревья разрезаются на короткие бревна. Процесс обрезки, поднимающий общую экономическую ценность деревьев на самый высокий уровень, является методом оптимального рассечения на бревна. Этот метод увеличивает экономическую ценность деревьев до 20%.

Для одного только дерева может быть разработано в качестве альтернативы множество вариантов рассечения на бревна. Для достижения оптимального результата, используются компьютерные методы, быстро оценивающие все альтернативы. Сетевой анализ, линейное программирование, динамическое и интуитивное программирование, наиболее широко используются среди этих методов. В Турции в производстве лесоматериалов метод оптимального рассечения на бревна не используется. Рассечение на бревна проводится исходя из опыта работников лесного хозяйства.

В данном исследовании, алгоритм оптимального рассечения на бревна был выведен, используя метод динамического программирования и язык программирования Microsoft Visual Basic v.6.3. Этот алгоритм был использован в производственных работах в лесах пихты киликийской (*Abies cilicica*) города Кахраманмараш, расположенного в восточной части Турции в регионе Средиземного моря. Затем результаты метода оптимального рассечения на бревна были сравнены с традиционными методами рассечения на бревна.

Полученные результаты показывают, что метод оптимального рассечения на бревна увеличил обьём деревьев в 4,18% и общую ценность в 9,31%. Статистический анализ показал значительные изменения в повышении ценности рассекаемых деревьев в зависимости от диаметра. Было обнаружено, что среднее значение и объемный прирост у высоких брёвен намного больше. Аналогичным образом, у деревьев с толстым диаметром среднее значение и объем выгоды оказался больше.

Ключевые слова: оптимальное рассечение на бревна, трелевка, оптимизация, пихта киликийская