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HARVEST SCHEDULING AND OPERATIONAL PLANNING FOR MOUNTAINOUS AREAS: A CASE STUDY FOR IKISU PLANNING UNIT

PLANIRANJE SJEČE I OPERATIVNO PLANIRANJE ZA PLANINSKA PODRUČJA: STUDIJA SLUČAJA PLANSKE JEDINICE IKISU

Erhan ÇALIŞKAN* Uzay KARAHALİL

Abstract

Harvest scheduling has emerged as time consuming and difficult activity especially when includes operation plans in the absence of decision support systems. In this study, the level of allowable cut and timber extraction system for every stand was determined for spruce management unit of a mountainous İkisu planning unit in Turkey using linear programming model designed for 50 year planning horizon. First, different considerations such as maximization of timber cut with non-exceeding more than a certain distance between the centroids of compartments and the nearest forest roads were taken into account in determining the level of harvest. Approximately 68,728 m^3 annual allowable cut was determined for the first period of planning horizon. Then, six different timber extraction systems were incorporated during the designation of timber extraction method for the first 10 year period of the planning horizon. These are man power, animal power, skidder, small size cable crane, medium size cable crane and sledge yarder. Different factors such as transport direction, slope, distance to forest road, efficiency or cost were also taken into account in decision making. Various planning strategies were developed, including maximization of profit, minimization of timber loss, under time restrictions and solved with LINDO software. One of the strategies was selected based on the availability of the machineries, legal arrangements, staff and economic conditions of the forest enterprise. According to the selected strategy (STR2), with the maximal total profit from timber production including time constraints less than 2,000 hours for cable cranes and sledge yarders, 6,365,205 € would be earned, 19,055 hours would be spent, and 1,697.8 m^3 timber would be lost, while 91.77 damage would occur. As a result this determination could bring us benefits especially in environmental awareness, time, labor and money when compared to the classical approaches.

KEY WORDS: forest management, harvest scheduling, operational planning, timber extraction systems, İkisu planning unit, Blacksea region

INTRODUCTION
UVOD

Forest management encompasses the economic and technical measures involved in the conservation and use of forests. It includes various degrees of intervention for the sustained production of goods and environmental services. While the objectives of management vary widely from the protection of forest resources to utilization, the primary objective has often been the production of wood products (FAO, 2016).

Assoc. prof. dr. Erhan Caliskan, dr. Uzay Karahalil, Karadeniz Technical University, Faculty of Forestry, 61080, Trabzon-Turkey
*caliskan@ktu.edu.tr

Determining the level as well as the sequence of compartments is a difficult issue to be resolved especially for large and mountainous areas. Moreover, after determining the harvest scheduling, another forestry problem arises as the determination of timber extraction system. Timber extraction defined as the transfer of wood material from compartment to the nearest forest road, is also seen as an important step in harvesting activities. Selecting the best timber extraction system according to different conditions emerges as a main planning problem for many forest managers especially working on hard terrain conditions (Pentek et al., 2008). They find it difficult to determine which system gives the highest profit, and which one takes the lesser time or requires minimum timber loss.

Various planning techniques such as linear programming, mixed integer programming, dynamic programming, genetic algorithm, tabu search or simulated annealing, have been widely used to accommodate harvest scheduling (Bettinger and Zhu, 2006; Heinonen and Pukkala, 2007; Karahalil et al., 2009; Fonseca et al., 2012; Hernandez et al., 2014; Zengin et al., 2015) or operational timber extraction problems (Lussier, 1959; Bell, 1977; Davis, 1987; Oborn, 1996; Kellogg et al., 1996; Acar et al., 2000; Chung et al., 2006; Eker and Acar, 2006; Flisberg and Rönnqvist, 2007; Bredström et al., 2010; Jaafari et al., 2015; Bont et al., 2015; Çalışkan and Karahalil, 2015; Ackerman et al., 2016).

However, very few studies have been conducted to combine two issues in one model and accommodate relatively large number of timber extraction systems. Different planning approaches such as minimizing cost, reducing timber loss or damage to the stands are performed simultaneously in this study. On the other hand, it is so important to offer many alternatives including harvest scheduling and operational planning with timber extraction system especially in mountainous areas. Therefore, the aim of this study is integrating harvest scheduling output and selecting optimum timber extraction system with a number of different scenarios including time, quantity, economic and environmental considerations for the part of mountainous İkisu planning unit in Turkey.

MATERIAL AND METHODS
MATERIJAL I METODE

Study area – *Promatrano područje*

The part of İkisu planning unit (PU) is selected as a study area located in Giresun, in the Northern Black sea region of Turkey (446500-451300 E and 4490700-4494100 N, UTM ED 50 datum Zone 37N). The study area is characterized by steep and rough terrain which stretches across a total area of 951.8 ha in the İkisu PU (34,195.1 ha). The av-

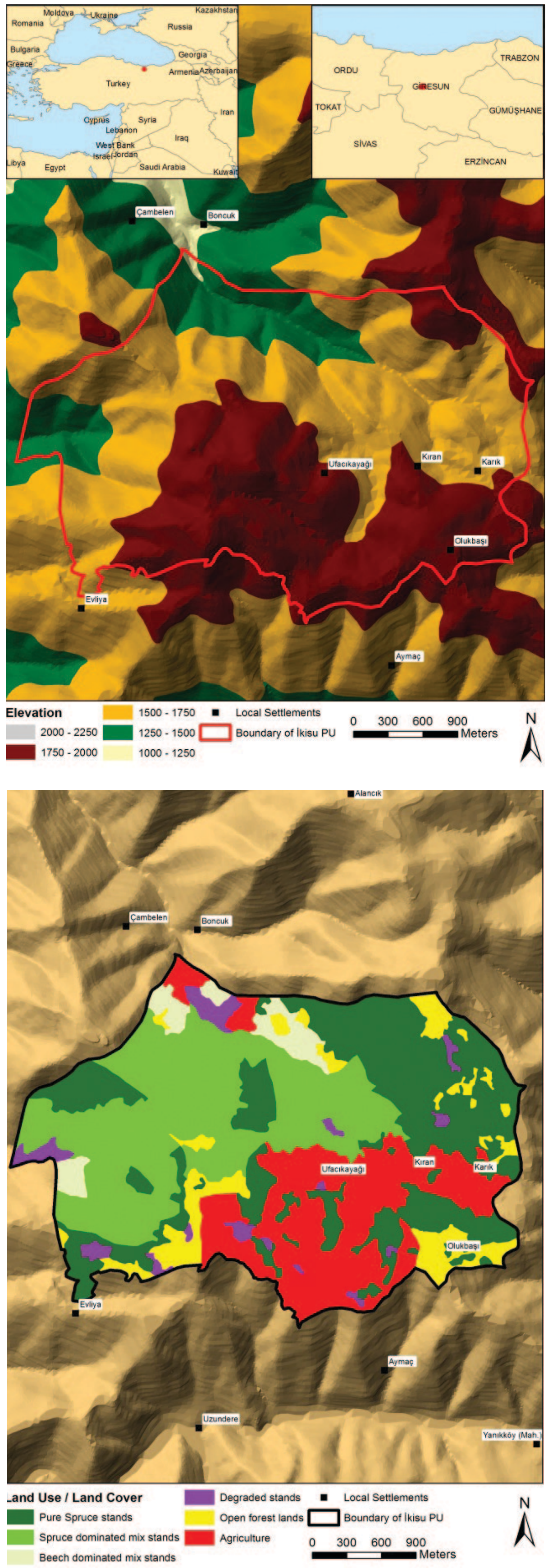

Figure 1. **Spatial location (a) and land use/ land cover map (b) of İkisu PU**

Slika 1. Prostorni smještaj (a) i karta iskorištavanja zemljišta/pokrivenosti zemljišta područja PJ İkisu erage terrain gradient is 37.4%, and altitudes range from 1,300 m to 1,900 m above sea level. (Figure 1a).

Study area has a total of 666.7 ha forested and 285.1 ha open lands. The forest within the study area belongs to government and is managed by Dereli State Forest Enterprise. The vegetation type of the study area is primarily composed of the association of Oriental Spruce *(Picea orientalis L.)*, Oriental beech *(Fagus orientalis Lipsky)*, and Caucasian fir *(Abies nordmanniana subsp. nordmanniana)* (GDF, 2013). The road length is 25,170 m within the study area, means that road density is 26.6 ha/m which is close to desired value as 20 m/ha (GDF, 2008). Therefore, road density and road spacing is sufficient for harvesting and other forestry activities. (Figure 1b).

Method of Approach – *Metoda pristupa*

In this study a two stage modelling approach was developed. The first stage was determined on the level of harvesting unit using linear programming with the aim of timber cut volume maximization. On the other hand, new forest road construction cost is very high nowadays considering steep terrain conditions (Sessions, et al., 1987; Allison et al., 2004; Enache et al., 2015). The mean forest road construction cost is approximately 7,238 €/km throughout the country, however, this cost is nearly two times higher as 13,442 € in the Blacksea region due to the mountainous and rocky conditions with high slopes (Çağlar and Türk, 2008). In another study, Acar and Eker (2001) found the road construction costs in Blacksea region two times more than costs in Lake region (near Isparta city) based on the six-year data, similar with previous study. Therefore, forest enterprise is not willing to spent more money because of budget constraints at least for the first period. A constraint was added to the linear programming model with minimizing the distance from the regeneration areas to the nearest forest road to reflect willingness of the forest enterprise. After obtaining the outputs, the results of the first period in terms of regeneration or thinning compartments and the level of harvest belong to those harvest areas were taken. Those parameters or outputs were used in the second stage as determining the timber extraction system.

Six main timber extraction systems are in use throughout the country as man power, animal power, skidder, small size cable crane, medium size cable crane and sledge yarder (Acar et al., 2000; Eker and Acar, 2006; Çalışkan and Karahalil, 2015). Oxen are used as animal power and MB Trac is used as skidder. Koller K 300, Urus MIII and Gantner were also used as small size cable crane, medium size cable crane and sledge yarder respectively. Due to the terrain conditions and high purchase costs, harvester machines are not used and other timber extraction systems such as plastic channels or monorail are not common and very limited. Therefore,

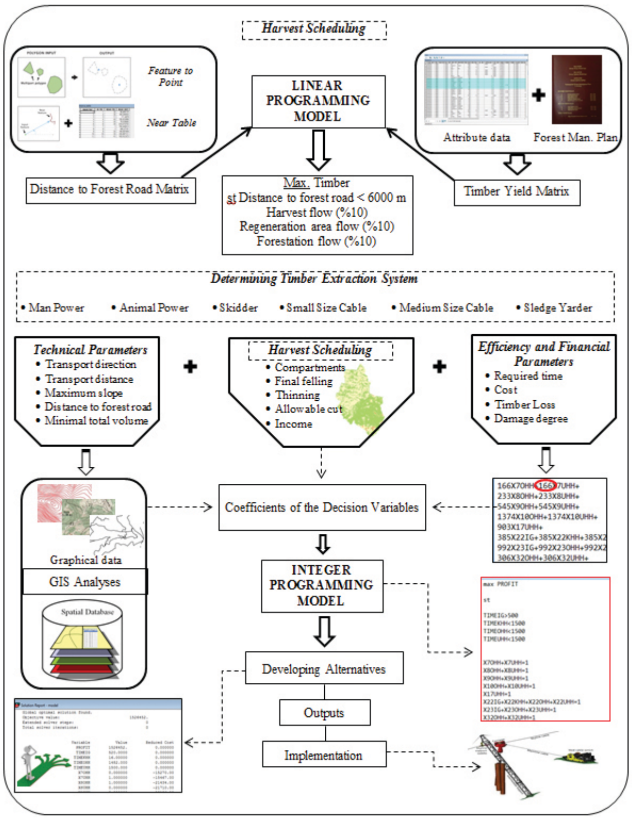

Figure 2. Conceptual framework of the research
Slika 2. Konceptualni okvir istraživanja

six types of timber extraction systems were considered in this study. In order to achieve the integration of different timber extraction systems in operation planning with a number of different scenario analyses considering time, quantity, economic and environment was tried. The developed conceptual framework is presented in the Figure 2.

Harvest Scheduling Stage – *Faza planiranja sječe*

To determine the level of harvest and assign the compartments to final felling or thinning, a 50 year linear programming model was developed for the study area. Stands were taken as the basic components of the model. MODEL I approach was used to develop linear programming model (Davis et. al., 2001). Planning period is determined for 10 years. Natural stands younger than 100 years were exempted from regeneration. Bare lands were allowed for forestation in any period during the planning horizon. The level of thinning of any stand was determined as the 10% of the growing stock of the related stand. On the other hand, degraded and loose canopy stands (canopy <40%) were only subject to thinning (GDF, 2014). Regenerated stands grow according to normal yield tables developed by Akalp (1978) and Carus (1998). Forest inventory data were updated to determine the current forest structure (forest composition) using İkisu forest management plan (GDF, 2013). Mid points of planning periods were used in calculation of yield curve data.

While one would generate tremendous number of strategies, we selected a reasonable one to test and understand operational planning toward a better solution. Maximum timber production was the main forest management goal in İkisu PU. Therefore, a planning strategy was developed with harvesting volume and forestation area flow constraints considering periods and solved with LINDO™ software. The following mathematical equations are used to build the model.

Objective Functions:

$$Z_{max} = H \quad \text{(Eq. 1)}$$

Subject to:

$$\sum_{j=1}^{n}\left(\sum_{i=1}^{m} a_{ij}x_{ij}\right) - H = 0 \quad \text{(Eq. 2)}$$

$$\sum_{i=1}^{m}\left(\sum_{j=1}^{n} x_{ij}\right) <= T_i \quad \text{(Eq. 3)}$$

$$\sum_{i=1}^{m} b_{i1}x_{i1} <= D \quad \text{(Eq. 4)}$$

$$\left(-(1-y)H_j + H_{j+1}\right) \geq 0 \quad \text{(Eq. 5)}$$

$$\left(-(1+y)RA_j + RA_{j+1}\right) \leq 0 \quad \text{(Eq. 6)}$$

$$\left(-(1+y)FA_j + FA_{j+1}\right) \leq 0 \quad \text{(Eq. 7)}$$

$$x_{ij} \geq 0 \quad \text{(Eq. 8)}$$

Where,

x_{ij} : Stand area i, regenerated in period j (ha)

m : Number of stands (i=1 to 129).

n : Silvicultural treatment options (j=1 to 5)

a_{ij} : Amount of one ha timber production value of stand i cut in period j (m^3)

b_{ij} : Distance of stand i to the nearest forest road that regenerated in the first period (m)

H : Total harvesting volume (m^3)

T_i : Stand area i (ha)

H_j : Total harvesting volume in period j (m^3)

RA_j : Final felling area in period j (ha)

FA_j : Forestation area in period j (ha)

D : Permitted total distance in the first period (m)

y : The change rate between periods (10%)

Operational Planning Stage – *Faza operativnog planiranja*

In order to achieve the integration of different timber extraction systems in harvest planning with a number of different scenario analyses considering time, quantity, economics and environment, a broad range of information was required. Harvest areas have different conditions such as; ground slope, volume, timber extraction direction or distance. In the meantime, the machines have different capacities, costs or efficiencies. Moreover, the planning of harvesting operations requires the consideration of restrictions or limitations of interested enterprise. Therefore, decision making techniques should be used, taking into consideration the different performance functions such as net income, time or timber loss as well as terrain or machinery conditions in the operational planning process (Acar et al., 2000; Bredström et al., 2010; Çalışkan and Karahalil, 2015). In this way, appropriate timber extraction method could be selected, needed to perform the operations at each harvest area or compartment to reach the desired goals under different restrictions.

Some factors such as working direction, slope limits, efficiency, costs or operation distance were found to be different

Table 1. Technical parameters of the selected timber extraction systems
Tablica 1. Tehnički parametri odabranih sustava privlačenja drva

System Sustav	Direction Smjer	Max. Slope (%) Maks. nagib (%)	Distance (m) Udaljenost (m)	Minimal total volume (m^3) Min. količina (m^3)
Man power *Ljudska snaga*	1	30-50	<500	0
Animal power *Životinjska snaga*	1	0-30	<500	0
Skidder *Šumski traktor*	1,2	0-100	<=100	0
Small size cable crane *Mala pokretna lančana dizalica*	1,2	0-100	<=300	300
Medium size cable crane *Srednja pokretna lančana dizalica*	1,2	0-100	>300, <600	300
Sledge yarder *Žičara*	1,2	0-100	<2000	300

Table 2. Efficiency and financial parameters of the selected timber extraction systems
Tablica 2. Učinkovitost i financijski parametri odabranih sustava za privlačenje drva

System *Sustav*	Efficiency (m³/hour) *Učinkovitost (m³/sat)*	Cost (€/hour) *Troškovi (€/sat)*	Timber Loss (%) *Gubitci (%)*	Damage Degree -*Stupanj štete*	
				Standing trees Dubećastabla	Saplings *Mladice*
Man power *Ljudska snaga*	0.74	26.87	17	1.73	1.92
Animal power *Životinjska snaga*	1.51	10.10	5	1.39	1.55
Skidder *Šumski traktor*	3.90	10.49	3	1.05	1.19
Small size cable crane *Mala pokretna lančana dizalica*	5.29	13.95	1	0.41	0.57
Medium size cable crane *Srednja pokretna lančana dizalica*	5.65	32.32	1	0.41	0.57
Sledge yarder *Žičara*	5.12	23.24	1	0.41	0.57

according to the selected system. Therefore, to calculate efficiency or cost coefficients of the decision variables, previously conducted studies were used (Aykut et al., 1997; Acar, 1997; Acar, 1998; Çağlar, 2002; Öztürk and Şentürk, 2006; Şentürk et al., 2007). Technical parameters of selected systems as man power, animal power (oxen), skidder (MB Trac), small size cable crane (Koller K 300), medium size cable crane (Urus MIII) and sledge yarder (Gantner), used in above mentioned literature are given in Table 1 and Table 2.

In order to calculate the required technical parameter information for each stand, Geographic Information Systems (GIS) were used with ArcGIS 10.2 ™ software. Geographic data used in this study were acquired from topographical maps produced by the General Command of Mapping of Turkey containing 10 m contour interval elevation data and digital stand type map. Forest road network, which is an important technical limitation for timber extraction systems, was also incorporated into the model. GIS queries or functions such as „TIN" (Triangulated Irregular Network) data „average slope" or „Generate Near Feature" were also handled in the determination of the working direction and calculating the maximum distances from the nearest forest roads. Similarly, it is important to keep the cost, time, loss of the amount of timber as low as possible. Moreover, it is generally known that forest soil, standing trees, and wild life were natively affected depending on the selected timber extraction system. These results or deterioration in forest lands have adverse effects on forest soils, erosion and environmental destruction (Fairweather, 1991; Ampoorter et al., 2007). Therefore, it is so essential to integrate environmental parameters into the harvesting planning process as well as efficiency and financial considerations. Considered parameters were taken from the mentioned literature given for technical parameters (Table 2).

Damage degree values ranges between 0 and 4, taken from Eroğlu et al. (2009). Damage degree of animal power system were not put into account in the study which has already been mentioned, therefore, the mean values of man power and skidder were used in animal power damage degree in this study. Timber loss quantities used in the model were taken from literature. For instance, timber loss from man power was taken as 17% (Gürtan, 1975). Other values were taken from Acar et al., (2000) previously estimated as 5%, 3% and 1% respectively for the animal power, skidder and cable cranes.

General Structure of the Timber Extraction Model – *Generalna struktura modela privlačenja drva*

In order to determine the best suitable timber extraction system, Integer Linear Programming (ILP) was used, as it is a powerful tool for generating an optimal solution which enables further sensitivity analyses (Oborn, 1996; Eker and Acar, 2006; Bont et al., 2015; Çalışkan and Karahalil, 2015). Different factors affecting timber extraction systems were integrated, and a number of operational planning strategies were developed to evaluate the trade-offs among timber extraction systems. Different planning strategies were developed with various characteristics and solved with LINDO™ software (LINDO, 2016).

Objective Functions:

$$Z_{max} = Profit;\ Z_{min} = Timber\ Loss;\ Z_{min} = Time;\ Z_{min} = Damage \quad \text{(Eq. 9)}$$

Subject to:

$$\sum_{j=1}^{n}\left(\sum_{i=1}^{m} a_{ij}x_{ij}\right) - Income = 0 \quad \text{(Eq. 10)}$$

$$\sum_{j=1}^{n}\left(\sum_{i=1}^{m} b_{ij}x_{ij}\right) - Cost = 0 \quad \text{(Eq. 11)}$$

$$Income\text{-}Cost\text{-}Profit=0 \quad \text{(Eq. 12)}$$

$$\sum_{j=1}^{n}\left(\sum_{i=1}^{m} c_{ij}x_{ij}\right) - TimberLoss = 0 \quad \text{(Eq. 13)}$$

$$\sum_{i=1}^{m} d_{i1}x_{i1} - T_{mp} = 0 \quad \text{(Eq. 14)}$$

$$\sum_{i=1}^{m} e_{i2}x_{i2} - T_{ap} = 0 \quad \text{(Eq. 15)}$$

$$\sum_{i=1}^{m} f_{i3}x_{i3} - T_{ft} = 0 \quad \text{(Eq. 16)}$$

$$\sum_{i=1}^{m} g_{i4}x_{i4} - T_{sscc} = 0 \quad \text{(Eq. 17)}$$

$$\sum_{i=1}^{m} h_{i5}x_{i5} - T_{mscc} = 0 \quad \text{(Eq. 18)}$$

$$\sum_{i=1}^{m} k_{i6}x_{i6} - T_{sy} = 0 \quad \text{(Eq. 19)}$$

$$T_{mp}+T_{ap}+T_{ft}+T_{sscc}+T_{mscc}+T_{sy}-Time=0 \quad \text{(Eq. 20)}$$

$$\sum_{j=1}^{n}\left(\sum_{i=1}^{m} l_{ij}x_{ij}\right) - Damage = 0 \quad \text{(Eq. 21)}$$

$$\forall i \sum_{j=1}^{n} x_j = 1 \quad \text{(Eq. 22)}$$

$$x_{ij} = 0 \vee 1 \quad \text{(Eq. 23)}$$

Where,

x_{ij}: Timber extraction system *j* to be applied in compartment *i* (man power, animal power, etc.)

a_{ij}: Income from compartment *i* using timber extraction system *j* (€)

b_{ij}: Costs in compartment *i* using timber extraction system *j* (€)

c_{ij}: The amount of timber loss from compartment *i* using timber extraction system *j* (m³)

d_{i1}: Required total time in compartment *i* using man power (hour)

e_{i2}: Required total time in compartment *i* using animal power (hour)

f_{i3}: Required total time in compartment *i* using skidder (hour)

g_{i4}: Required total time in compartment *i* using small size cable crane (hour)

h_{i5}: Required total time in compartment *i* using medium size cable crane (hour)

k_{i6}: Required total time in compartment *i* using sledge yarder (hour)

l_{ij}: Environmental damage in compartment *i* using timber extraction system *j* (hour) (ranges from 1 to 4)

Accounting variables:

Income: Total income (€)

Cost: Total cost (€)

Profit: Total profit (€)

Loss: Total timber loss (m³)

Time: Total spent time (hour)

T_{mp}: Total spent time for man power (hour)

T_{ap}: Total spent time for animal power (hour)

T_{ft}: Total spent time for skidder (hour)

T_{sscc}: Total spent time for small size cable crane (hour)

T_{mscc}: Total spent time for medium size cable crane (hour)

T_{sy}: Total spent time for sledge yarder (hour)

Damage: Total damage factor

m: Number of compartments (*m*=1 to 20)

n: Timber extraction systems (*n*=1 to 6; 1=man power, 2=animal power, 3=skidder, 4=small size cable crane, 5=medium size cable crane, 6=sledge yarder)

Developing Alternative Operational Planning Strategies – *Razvoj drugih strategija operativnog planiranja*

A number of operational planning strategies were developed to examine the options or planning opportunities and to reflect the sensitivity of various constraints. Few reasonable ones were selected to test and understand changes toward a better solution (Table 3).

Among the three strategies, STR1 maximizes the net profit from timber production considering timber extraction systems at the end of the planning period. This strategy has no constraints in terms of time, damage or income level.

Table 3. Descriptions of the operational planning strategies tested
Tablica 3. Opisi testiranih strategija operativnog planiranja

Strategies *Strategije*	Objective Function *Ciljna funkcija*	Constraints *Ograničenja*
STR1	Max Profit *Maks. profit*	no constraints *nema ograničenja*
STR2	Max Profit *Maks. profit*	T_{sscc}<2,000 and T_{mscc}<2,000 and T_{sy}<2,000
STR3	Min. Damage *Min. šteta*	T_{sscc}<2,000 and T_{mscc}<2,000 and T_{sy}<2,000

Similarly, STR2 has the same objective as maximizing net profit. However, STR2 has constraints as 2000 working hours for the selected timber extraction systems as small size, cable cranes, medium size cable cranes and sledge yarders respectively. On the other hand, STR3 minimizes the total damage from timber extraction activities at the end of the period with 2000 working hour constraints on small size, cable cranes, medium size cable cranes and sledge yarders.

RESULTS AND DISCUSSION
REZULTATI I RASPRAVA

Approximately 68,728 m^3 annual allowable cut was determined for the first planning period. The outputs of the model were given in Table 4. While the allowable cut and regeneration area followed an increasing pattern, on the other hand, forestation was gradually decreased because of the 10% flow constraints. As the other periods were not considered in terms of limiting the distance from the harvesting areas to the nearest forest road, „distance to forest road" values are unavailable for the further periods. Spatial locations of the stands subject to regeneration or thinning activities in the first period in İkisu was also given in Figure 3.

When all operational planning strategies are considered, the highest profit was obtained from STR1 followed by STR2, as 6.4 million € and 6.3 million € respectively. STR3 and STR2 yielded the highest cost, as 501.6 thousand € and 298.1 thousand €. Strategies that generated the lowest time are STR1 (15,057 hours) and STR2 (19,055 hours). Total timber loss was the minimum in STR1 (952.9 m^3) followed by STR2 (1,697.8 m^3), and finally maximum total damage was yielded by STR2 as 91.77 (Table 5).

Table 4. Outputs of the harvest scheduling model
Tablica 4. Rezultati modela planiranja sječe

Outputs *Rezultati*	Periods – *Razdoblja* 1	2	3	4	5
Allowable cut (m^3) *Etat*	68,728	75,601	83,161	91,477	100,625
Final felling area (ha) *Regeneracijsko područje*	113.8	122.0	132.3	145.5	160.1
Forestation area (ha) *Područje pošumljavanja*	19.0	17.1	15.4	13.8	12.4
Distance to forest road (m) *Udaljenost od ceste*	6,000	–	–	–	–

Planning strategies were also compared to each other in terms of time consumption, considering each timber extraction systems at the end of the planning period. These results indicated that STR2 and STR3 used the upper limits in both cable cranes and sledge yarder. On the other hand, spent time causes fluctuation in man power, animal power and skidder in a wide range in relation to objective function and constraints (Table 6).

Table 6 shows total spent time outputs considering each timber extraction system. Therefore, 1,451 hours used as man

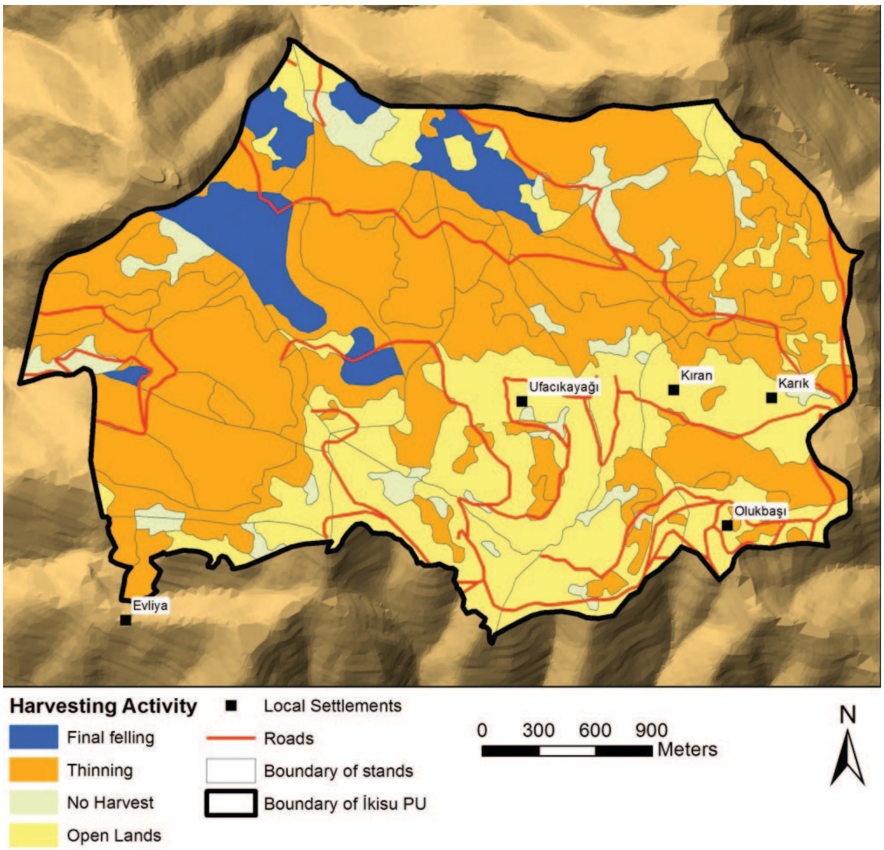

Figure 3. Spatial locations of the stands subject to harvesting activities in Ikisu PU
Slika 3. Prostorni smještaj sastojine podložne sječi u PJ Ikisu

Table 5. Some outputs of various operational planning strategies
Tablica 5. Neki rezultati različitih strategija operativnog planiranja

Strategies *Strategije*	Profit (€) *Profit (€)*	Cost (€) *Troškovi (€)*	Time (hour) *Vrijeme (sat)*	Timber Loss (m^3) *Gubitci (m^3)*	Damage *Šteta*
STR1	6,474,087	262,787	15,057	952.9	79.59
STR2	6,365,205	298,146	19,055	1,697.8	91.77
STR3	6,038,924	501,636	24,178	2,514.4	84.98

Table 6. Time outputs of the timber extraction systems (hours)
Tablica 6. Vremenski rezultati sustava privlačenja drva (sati)

Strategies *Strategije*	Man Power *Ljudska snaga*	Animal Power *Životinjska snaga*	Skidder *Šumski traktor*	Small Size Cable Cr. Mala pok. lan. diz.	Medium Size C.C. Srednja pok. lan. diz.	Sledge Yarder *Žičara*
STR1	1,451	712	642	8,119	–	4,133
STR2	1,451	4,030	7,616	1,984	1,974	2,000
STR3	10,305	679	7,246	1,984	1,991	1,973

power for the STR2 refers that, when you implement STR2, 1,451 hours man power will be spent with other timber extraction systems such as 1451 hours as man power, 4,030 hours as animal power, 7,616 hours as skidder and so on in the period 1 to extract all the timber within the planning unit. These time outputs should be considered together for the first period of STR2. Those time outputs are not separate, meaning that all time outputs for the STR2 will be spent when STR2 is implemented. The outputs are not refer that 1,451 hours for man power or 4,030 hours for animal power will spent separately to extract all the timber within the planning unit.

When we look at the timber extraction methods to be applied, „S" seems prevailing in STR2. On the other hand, there was no prominent timber extraction system in other strategies, (Table 7).

Many factors such as legal arrangements, supply and demand, staff and economic conditions of the enterprise must be taken into consideration when determining the appro-

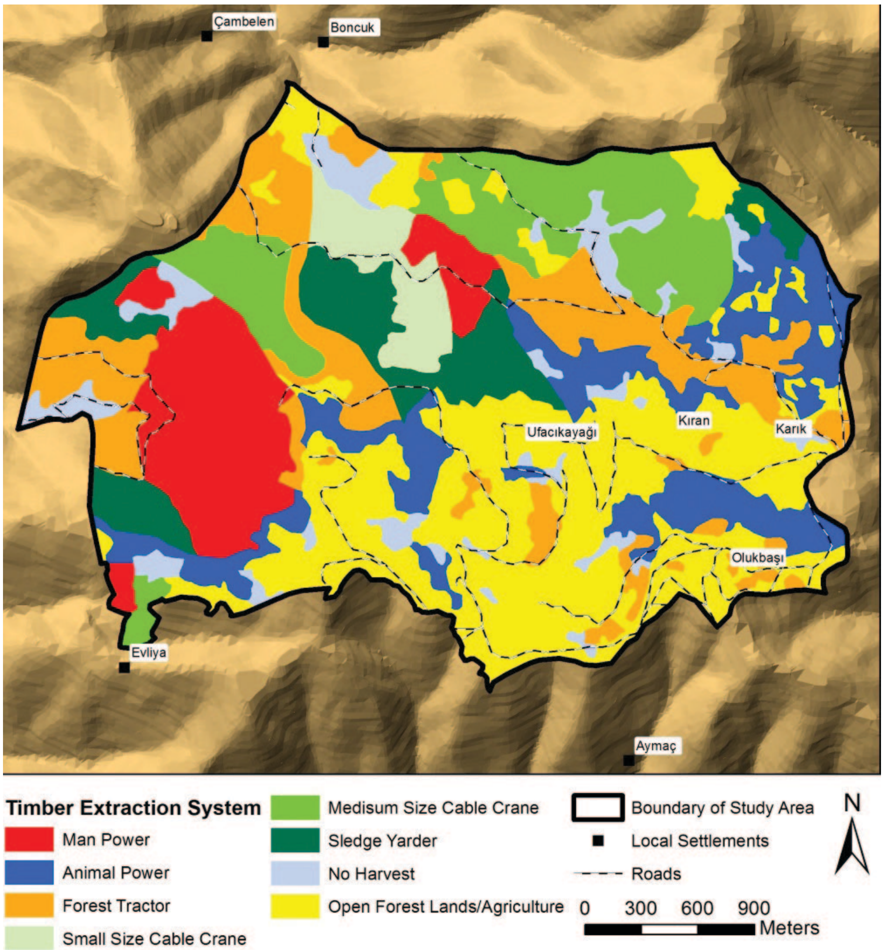

Figure 4. Timber extraction methods according to STR2
Slika 4. Metode privlačenja drva prema STR2

Table 7. Timber extraction methods according to compartments
Tablica 7. Metode privlačenja drva prema odjeljcima

	Stand No *Sastojina br.*	Timber Extraction System *Metode privlačenja drva*				Stand No *Sastojina br.*	Timber Extraction System *Metode privlačenja drva*		
		STR1	STR2	STR3			STR1	STR2	STR3
Final felling – *Regeneracija*	16	SY	MSCC	SSCC	Thinning – *Prorjeđivanje*	61	SY	MSCC	MSCC
	17	SSCC	S	S		62	S	S	S
	18	SSCC	S	S		63	SY	SY	SY
	19	SSCC	S	SY		64	MP	MP	MP
	83	MP	MSCC	MP		65	S	S	S
	84	SSCC	S	S		66	AP	AP	S
	102	SSCC	S	S		67	SSCC	AP	SY
	103	SSCC	S	S		68	S	S	S
	104	SSCC	SSCC	SSCC		69	S	S	S
	105	SSCC	S	S		70	SY	AP	MSCC
Thinning – *Prorjeđivanje*	20	SSCC	S	SY		71	AP	AP	AP
	21	AP	AP	AP		72	S	S	S
	22	MP	MP	MP		73	SSCC	AP	SY
	23	S	S	S		74	S	S	S
	24	S	S	S		75	S	S	S
	25	S	S	S		76	S	S	S
	26	S	S	S		77	S	S	S
	39	AP	AP	AP		78	AP	AP	AP
	40	S	S	S		79	S	S	S
	41	S	S	S		80	SY	MSCC	SY
	42	MP	MP	MP		81	SSCC	SSCC	SSCC
	43	S	S	S		82	MP	MP	MP
	44	S	S	S		85	SSCC	SY	SY
	45	S	MP	AP		86	SSCC	AP	SY
	46	AP	AP	AP		87	SSCC	S	S
	47	S	S	S		88	SSCC	SY	SY
	48	S	S	S		89	SSCC	AP	SY
	49	S	S	S		90	SY	SY	SY
	50	S	S	S		91	MP	MP	MP
	51	S	S	S		92	MP	MP	MP
	52	S	S	S		93	MP	MP	MP
	53	S	S	S		94	MP	MP	MP
	54	S	S	S		95	MP	MP	MP
	55	AP	AP	AP		96	MP	MP	MP
	56	SY	MSCC	MSCC		97	SSCC	SY	SY
	57	S	S	S		98	S	S	S
	58	SY	AP	MSCC		99	S	S	S
	59	SY	SY	SY		100	MP	MP	MP
	60	S	S	S		101	SSCC	S	SY

*MP: Man Power, AP: Animal Power, S: Skidder, SSCC: Small Size Cable Crane, MSCC: Medium Size Cable Crane: SY: Sledge Yarder

priate strategy to implement (Naesset et al., 1997; Nielsen et al., 2007; Moseley et al., 2011). For instance, a cable crane or sledge yarder could work only 2000 hours in a year considering climate conditions, holidays, maintenance or installation and dismantling periods. This information was collected from forest enterprise and timber extraction contractors. Moreover, it is quite difficult to use two machines which have the same features at the same time, due to the high demand from other forest enterprises. This is more problematic for sledge yarders considering the potential numbers and high demand due to the extreme topographic conditions and low road density in Black sea region. Among the three strategies, the second strategy (STR2) with the maximal total profit from timber production including time constraints less than 2,000 hours for cable cranes and sledge yarders can be selected for the above reasons. These constraints allow the working of one machine for each type. When this strategy is implemented, earned revenue of 6,365,205 €, 19,055 hours spent, and 1,697.8 m^3 timber will be lost, while 91.77 damage will occur. The representation of the optimal solution with the help of GIS was given in Figure 4.

When looked at conducted similar studies investigating appropriate timber extraction systems, Acar et al., (2000) suggested, combination of 4% human power, 36% skidder and 60% small size cable crane model, minimizing the cost of logging operations among 13 models. However, only one objective as minimization of cost was selected and animal power besides sledge yarders were not considered in this study. Minimum cost was found to be 491,282 € with the losses of quantity were 2500 m^3 in a 9764 ha study area in the same region. In another study, Eker and Acar (2006) developed an operational harvest planning methodology including both felling and timber extraction systems that was suitable for topographical and technical, acceptable for economic constraints, sensitive for forest ecosystems. Sledge yarders were not considered when compared to this study, however, plastic channels were taken into account. The developed model minimized the annual average unit cost from %4 to % 30. Pentek et al., (2008) tested a model for selecting an ecoefficient harvesting system for commercial forests based on three influencing factors as terrain slope, extraction distance and breast height diameter of trees. Felling and timber extraction systems were both determined for each forest sub compartment similar with this study. Skidder was the most frequently used timber extraction systems as 74% of the study area. That was followed by forwarder (14%), cable crane (11%), and helicopter (1%). Although mentioned studies conducted under different typographic, economic, efficiency and technical conditions, they provide us sound information for the comparison. In this study, cable systems (small size, medium size and sledge yarders) were the leading timber extraction system (35%), flowed by skidder (23%), animal power (19%) and man power (5%) when considering outputs of STR2 in terms of area. However, 8% of the study area was not assigned to a timber extraction system due to the typographic or technical limitations.

CONCLUSIONS
ZAKLJUČCI

This study is out to combine harvest scheduling and operational planning approach with an attempt to enhance planning of timber extraction methods, according to terrain and management conditions. Six timber extraction methods were used: man power, animal power (oxen), skidder (MB Trac), small size cable crane, medium size cable crane and sledge yarder were integrated in an operational model using integer linear programming technique. The model that was presented here produced solutions for a selected mountainous forest in Black sea region of Turkey, with different alternatives, but all including environmental concerns, unlike the present conventional approach, time restrictions as well as economical parameters.

Parameters such as income, costs, total spent time, timber loss and stand damage were characterized quantitatively, according to different timber extraction systems. The data infrastructure was generated using GIS environment. Contrary to conventional methods, alternative operational planning strategies were developed and many options were presented to decision maker to make the best and accurate decisions. At the end of the production period, providing conditions such as spent time from certain extraction methods at target levels, maintaining time flow for selected cable systems and achieving maximum profit were satisfied. Thus, the developed model allowed us to handle multiple scenarios, each with different dimension sizes, that may prove extremely useful in gaining possible results before system implementation, and to of course compare the outputs and to decide of re-planning if it is required. This kind of differential planning has a positive effect because decision maker can obtain outputs from various scenarios in a »reasonable amount of time« and get workable solutions.

Approximately 68,728 m^3 annual allowable cut was determined for the first period of planning horizon. Among the developed alternatives, STR2 was selected for maximizing total profit and including constraints less than 2,000 hours for cable cranes and sledge yarders due to the availability of the machineries, staff and economic conditions of the enterprise. If this strategy is to be implemented, 6,365,205 € could be earned, 19,055 hours could be spent, and 1,697.8 m^3 timber could be lost, while 91.77 damage could occur.

Similar studies should be expanded with the preparation of timber extraction plans and should be integrated into forest management plans as well as silviculture plans. As multiple timber extraction systems are presented to forest enterprise, operational plans must be prepared with operations research techniques. Different data affecting the selection of timber extraction system should be brought together as well as environmental concerns such as soil conservation or biodiversity provided with different forestry disciplines, and those data should be digitized according to timber extraction systems and in this way, these values must be integrated to operational plans numerically.

In conclusion, modeling is an inevitable tool in accommodating both harvest scheduling and timber extraction systems in operational planning. Considering different parameters such as cost, income, consumption time, loss or damage of the wood, extraction systems can provide a wide range of opportunities to the forest managers.

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Sažetak

Planiranje sječe dugotrajna je i zahtjevna aktivnost, posebice kad uključuje operativne planove bez sustava za donošenje odluka. Ovime se istraživanjem odredila razina etata i sustavi privlačenja drva za svaku sastojinu u jedinici za upravljanje smrekovom šumom u planinskoj jedinici İkisu u Turskoj pomoću modela linearnog programiranja napravljenog za vremenski horizont planiranja od 50 godina. Prvo, kako bi se odredila razina sječe, razmatrala se maksimizacija debla koja ne prelazi određenu udaljenost od centroida odjeljka i najbliže ceste. Za prvi period vremenskog horizonta planiranja određen je godišnji etat od otprilike 68728 m^3. Zatim je uključeno šest različitih sustava za privlačenje drva tijekom određivanja metode privlačenja drva za period od prvih 10 godina horizonta planiranja. To su ljudska snaga, životinjska snaga, šumski traktor, mala pokretna dizalica, srednja pokretna dizalica i vitlo na saonicama. U donošenju odluka također su razmatrani različiti čimbenici kao što su smjer transporta, nagib, udaljenost od ceste, učinkovitost ili troškovi. Razvijene su različite strategije planiranja, uključujući maksimizaciju profita, minimizaciju gubitaka u proizvodnji, vremenska ograničenja, te su problemi riješeni pomoću sustava LINDO™. Jedna od strategija odabrana je temeljem dostupnosti strojeva, zakonskih rješenja, osoblja i ekonomskih uvjeta šumarije. Prema odabranoj strategiji (STR2), uz maksimalni ukupni profit od proizvodnje debla, uključujući vremensko ograničenje od manje od 2000 sati rada žičare i vitla na saonicama, zaradit će se 6365205 €, potrošit će se 19055 sati, i izgubit će se 1697.8 m^3 debla te će nastati šteta od 91.77. Kao rezultat, ta odluka bi mogla donijeti i koristi, posebice u ekološkoj svijesti, vremenu, radu i novcu kada se usporedi s klasičnim pristupima.

KLJUČNE RIJEČI: upravljanje šumom, planiranje sječe, operativno planiranje, sustavi privlačenja drva, planska jedinica İkisu, regija Crnog mora