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ASSESSMENT OF POST-FIRE SALVAGE LOGGING OPERATIONS IN MEDITERRANEAN REGION OF TURKEY

PROCJENA AKTIVNOSTI SANACIJSKE SJEČE NAKON POŽARA U MEDITERANSKOM PODRUČJU TURSKE

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Summary

Various problems such as massive volume loss, erosion, degradation of water resources, and air pollution emerge after forest fire incidents. Thus, necessary forest operations should be quickly planned and implemented after forest fires so that afforestation activities can take place immediately to maintain forest vegetation in burned areas. The aim of this study was developing a Post-fire Action Planning (PFAP) model to minimize the time spent on salvage logging activities. PFAP model will assist decision makers for removing salvage timber in a timely manner after large scale forest fires, while considering economic and environmental constraints, and dealing with available employment conditions in local forest industry. The capabilities of this model were examined by standardizing the operational planning and developing a fast decision-making process. The model was implemented in Taşağıl Forest Enterprise Chiefs (FEC) of Antalya Forest Regional Directorate where the forests are sensitivity to fire at the first degree level and the second largest forest fire in the history of Turkish Forestry occurred in this area in 2008. The findings of PFAP model were compared with the data of actual salvage logging operation obtained from the FEC. The results indicated that using operational planning based PFAP model is capable of reducing total time spent on salvage logging operation by about 60%. Based on the forestry compartments of the study area, estimated durations of salvage logging operations were 15 to 75 days less than that of actual operations taken place in the field. Therefore, it is highly anticipated that using operational planning based PFAP model has great potential to provide economically and environmentally sound forest operations after forest fires.

KEY WORDS: Forest fire, Salvage logging, Forest transportation, Operational Planning, Modelling

1. INTRODUCTION
1. UVOD

The continuity of forest resources are subject to great threat due to detrimental effects of natural disasters (i.e. wild fires, winter storms, avalanches) and impacts of anthropogenic factors (i.e. illegal forest harvesting, unsuitable land use changes, excessive usage of forest resources). Among these threats, forest fire is one of the crucial factors that seriously damages forest resources and negatively affects sustainable management of forest resources, which then leads to biological and ecological destructions on forest ecosystems (Bilici, 2009).

Forest fires are considered as main sources of greenhouse gasses (i.e. CO_2, CH_4, ect.) emitted to the atmosphere (Guido

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et al., 2004). Besides, fire damaged trees become more vulnerable to deterioration agents such as insects and fungus (Akay et al., 2007). Forest fires result in important amount of economic value loss on forest products and this loss tends to increase as they stay longer in the forests before salvage logging operation starts. Therefore, in order to reduce these negative effects after forest fires, post-fire salvage logging operations should start immediately to extract fire damaged timber and make the site ready for regeneration activities.

The time spent on planning and implementation of salvage logging operations is mainly limited by the urgency of necessary revegetation activities at the site, value loss of forest products as time passes after fire, and expected attacking time of deterioration agents. To minimize the time spent on salvage logging operations especially after large scale forest fires, Post-fire Action Planning (PFAP) model can be used to overcome these types of complex problems, while considering various economic and environmental constraints. Operational planning approach and decision support systems are common methods to efficiently develop such models for optimal usage of forest products.

In the previous studies, operational planning approaches and decision support systems have been widely used in forest operation planning studies. Eker (2004) developed an operational planning method in which mathematical model was developed by using linear programming and integer programming techniques to plan forest harvesting activities. In another study, Akay (2009) used dynamic programming based stem-level optimum bucking algorithm to investigate the effects of forest harvesting techniques (manual skidding vs. ground based mechanized skidding) on optimum bucking method by considering the maximum allowable log lengths.

Operational planning approach and decision support systems have been also used in post-fire salvage logging operation studies. Akay et al. (2006) developed a computer programming based model to evaluate productivity and cost of helicopter logging system for extraction of fire damaged trees after forest fire. The decision variables in the model included tree diameters, log position within the tree stem, yarding distance, and time since tree death. They stated that salvage logging operation should be planned and performed promptly to recover the maximum economic value of fire damaged trees.

In order to determine the management and strategies in forestry, decision support systems are often used in previous studies. Reynolds (2005) used simulation for small private holdings to cooperative management across multiple ownerships. Zeng et al. (2007) used simulation method assessing the short- term and long-term risk of wind damage in boreal forests (i.e. stand and regional level). Lineer Programming and Mixed Integer Programming were used for strategic and tactical forest planning applications by Andersson and Erikssonn (2007). In another example, fuzzy set theory was employed for effective fire management planning (Kaloudis et al. (2008).

Drosos et al. (2008) conducted a study where post-fire data were evaluated by using geoinformatic models. They organized post-fire salvage logging operations by generating optimized road network based on Digital Terrain Model. Karantzidis et al. (2008) analyzed environmental effects of logging operations after forest fires. They stated that post-fire salvage logging operations cause reduced impact on forest ecosystem especially during skidding activities which are more suitable with environmental conditions.

Eker and Çoban (2009) introduced general framework of logging and transportation planning model for post-fire forest operations. They also described system structures and capabilities of the model. In a follow up study, they tested effectiveness of new roads and existence roads during post-fire forest operations (Çoban ve Eker, 2010). Öztürk et al. (2011) conducted a study where performances of modern harvesting equipment were evaluated during post-fire salvage logging operations. It was reported that using modern equipment potentially improves working conditions and increases productivity comparing with traditional logging methods.

In this study, A Post-fire Action Planning (PFAP) model was developed to determine optimum operation techniques that minimize the time spent on extraction of salvage timber and reduce environmental impact after forest fires. Multi-criteria analysis was used to evaluate many work stages of salvage logging operations, while considering ecological, economic, and social constraints. Then, the model was implemented in Taşağıl Forest Enterprise Chiefs (FEC) of Antalya Forest Regional Directorate in Mediterranean region of Turkey.

2. MATERIAL AND METHODS
2. MATERIJALI I METODE

2.1. Study Area –
2.1. Područje mjesto istrazivanja

In order to select the most appropriate study area, large forest fire incidents taken place in Turkey were evaluated within the archive of General Directorate of Forestry (GDF). Serik-Taşağıl fire, in which 15795 ha forested area was burned in 2008, was selected as the study case (Figure 1). This fire was the second largest forest fire in the history of Turkish Forestry and caused serious damages on four FECs including Akbaş, Karabük, Sağırın, and Taşağıl in the city of Antalya (Figure 2). The forests are sensitivity to fire at the first degree level and the dominant tree species was Brutian pine (*Pinus brutia* T.) in the region. The forest stand characteristics in these FECs are listed in Table 1.

Figure 1. Fire fighting activities (Photo: M. Eker)
Slika 1. Protupožarne aktivnosti (Foto: M. Eker)

The study area was selected from fire damaged forests located within the border of Taşağıl FEC. The study area consisted of 1902 ha of high forest, 740 ha of unproductive forest, and 1285 ha of unforested area. After field reconnaissance and office work, total of 20 forest compartments were selected from burned areas based on size and severity of the damage (Figure 3). The compartments of datas are given in Table 2.

2.2. Field Study and Data Collection – *2.2. Terensko istraživanje i prikupljanje podataka*

The operational information about post-fire salvage logging applications in the study area were obtained by interviewing with forest engineers, forest rangers, and forest workers who attended extraordinary timber extraction operations after Serik-Taşağıl fire. During these interviews,

Table 1. The forest stand characteristics in fire damaged FECs
Tablica 1. Karakteristike šumske sastojine u šumarijama oštećenima požarom

FECs *Šumarije*	Forested Areas *Pošumljena područja*			Unforested Areas *Nepošumljena područja*		
	High Forest (ha) *Visoka šuma*	Unproductive Forest (ha) *Neobrasla šuma*	Total *Ukupno*	Open Land (ha) *Otvoreno zemljište*	Other Landuse Types (ha) *Ostale vrste korištenja zemljišta*	Total *Ukupno*
Akbaş	3904.0	1591.5	5495.5	11.5	2146.5	2158.0
Karabük	2591.5	582.0	3173.5	13.5	28.0	41.5
Sağırın	4003.5	480.5	4484.0	–	1273.0	1273.0
Taşağıl	1902.0	740.0	2642.0	3.5	1281.5	1285.0
Total Šumarije	12401.0	3394.0	15795.0	28.5	4729.0	4757.5

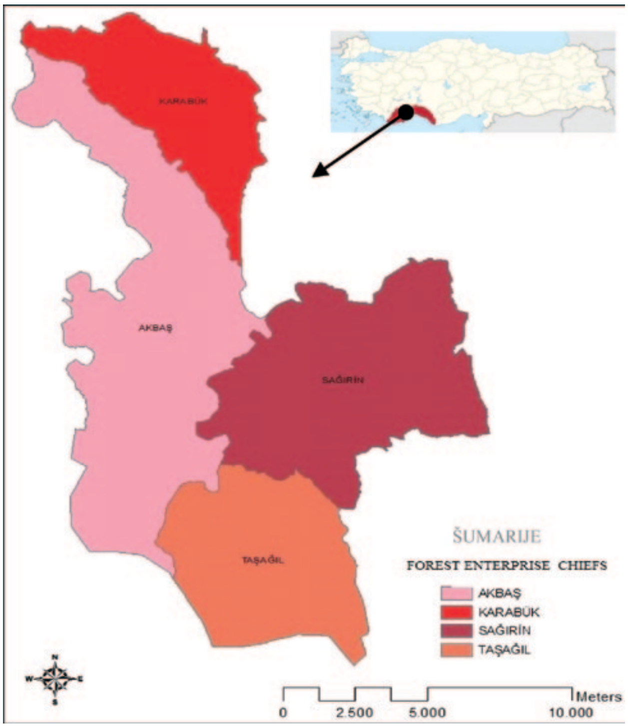

Figure 2. The FECs damaged by Serik-Taşağıl forest fire
Slika 2. Šumarije oštećene šumskim požarom Serik-Taşağıl

Table 2. Features of the Selected Compartments
Tablica 2. Značajke odabranom odjeljaka

No	Compartments	Area (ha)	Volume (m^3)	Slope (%)
1	277	47.5	2121.245	44
2	278	41.0	1877.226	52
3	279	21.0	961.506	48
4	280	25.0	1144.650	42
5	308	63.5	3224.229	45
6	310	41.0	5706.533	55
7	312	53.0	4005.659	60
8	313	33.0	2914,260	60
9	314	41.0	2824.000	50
10	315	46.0	3247.876	38
11	316	65.0	1818.643	46
12	317	71.0	2292.214	40
13	318	71.0	2954.926	42
14	319	44.0	1995.956	48
15	320	35.0	1522.962	34
16	321	34.0	1556.724	36
17	358	69.5	2826.478	40
18	360	48.0	1156.793	35
19	371	34.0	1373.580	48
20	372	35.5	1634.620	48

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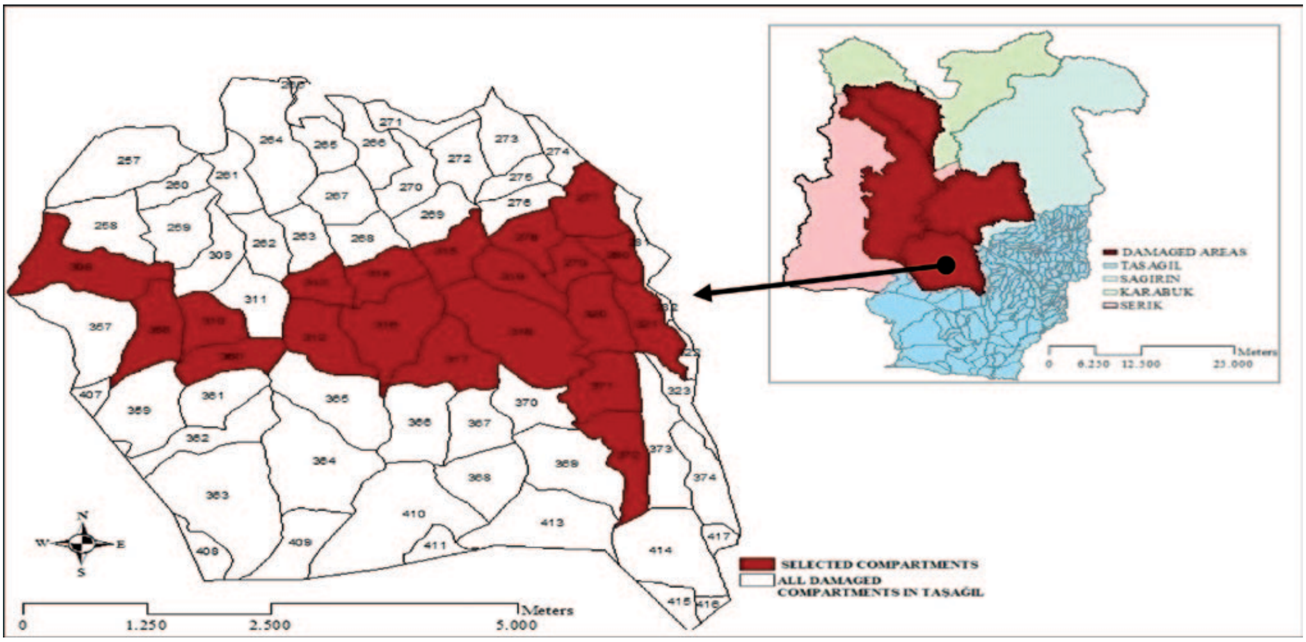

Figure 3. Areas damaged by Serik-Taşağıl fire and selected forest compartments in Taşağıl FEC
Slika 3. Područja pogođena požarom Serik-Taşağıl te odabrani šumski odjeljci u šumariji Taşağıl

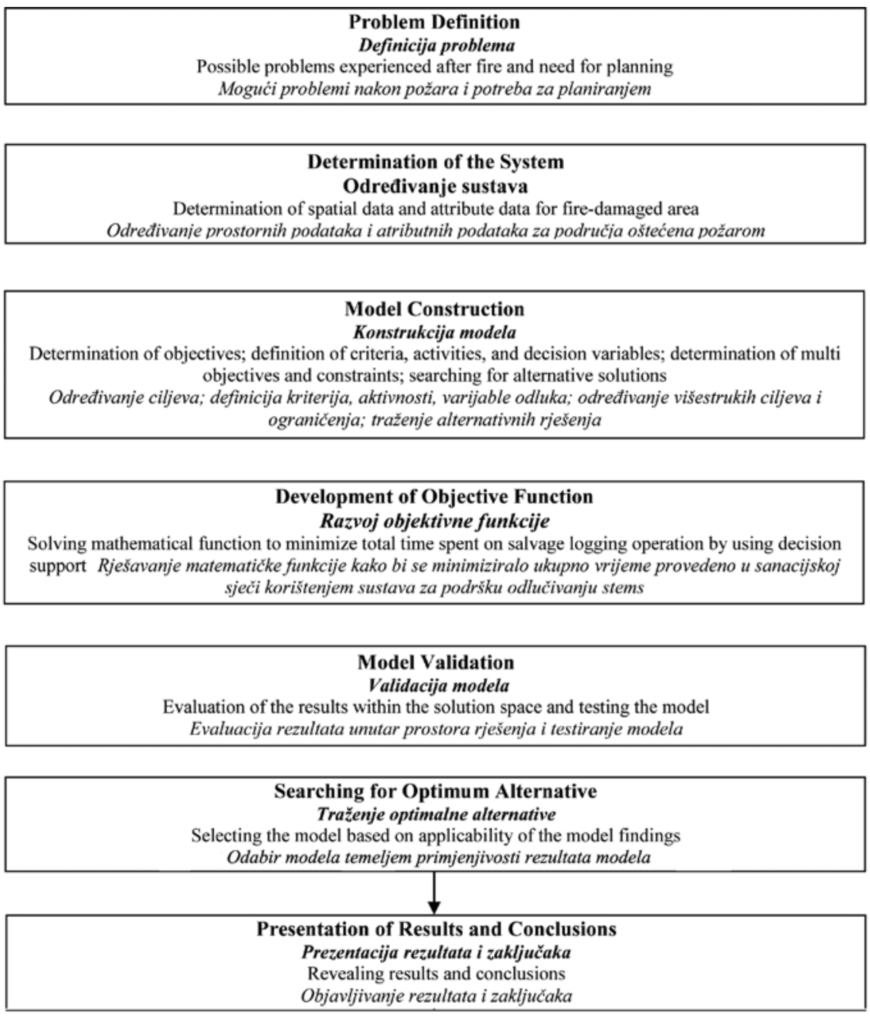

Figure 4. Flowchart of developing Post-fire Action Planning (PFAP) model
Slika 4. Dijagram toka modela planiranja aktivnosti nakon požara

Formula (1):

$$Z_1 min = \sum_c C = \left[\!\left[\sum_s S = \sum_g G = [\![DA]\!]_{csg} \cdot A_{cs} \right]\!\right] + \sum_c C = \left[\!\left[\sum_s S = \sum_t T = F_{cst} \cdot V_{(cst)} \right]\!\right] + \sum_c C = \left[\!\left[\sum_s S = \sum_t T = [\![TE_{cst} \cdot V_{cst}]\!] \right]\!\right] + \sum_c C = \left[\!\left[\sum_s S = \sum_t ST = H_{cst} \cdot V_{cst} \right]\!\right] + \sum_c C = \left[\!\left[\sum_s S = \sum_t T = RC \right]\!\right]_c$$

especially information about salvage logging planning after fire, logging practices, and workforce were recorded. The study area was investigated by field reconnaissance and visual data were taken for office evaluations. Besides, forest activities which were implemented based on “Rehabilitation of Burnt Forest Areas and a Fireproof Forest Facility Project” were examined in the field. This project, in fact, was initiated by GDF after Serik-Taşağıl forest fire and firstly implemented in this region (GDF, 2008). Salvage logging reports and extraordinary timber extraction data obtained from FEC were reorganized by using MS Excel program. One of the methodologies used and studied is the Analytic Hierarchy Process (AHP) proposed by Saaty (1980) in the early eighties. AHP significantly helps decision makers on multi-criteria and multi-alternative problems to finalize the decision process. The first step in the AHP is to develop a graphical representation of the problem in terms of a goal, criteria, and alternatives. Then, data were managed in order to be imported and run in mathematical optimization programs such as LINDO, MATLAB, WINOSB, and CPLEX. Among those, LINDO is mostly used mathematical program with key tools for analysis of stochastic and global optimizations, linear and nonlinear optimizations, linear-integer and nonlinear-integer optimizations, and infeasible linear, integer and nonlinear models (LINDO, 2010).

2.3. Operational Planning Approach – *2.3. Pristup operativnog planiranja*

Forest managers usually aim to extract fire-damaged timber from the stand in the shortest amount of time possible in order to initiate post-fire regeneration activities and to prevent deterioration of timber caused by fungus and insects. In this study, operational planning approach was implemented for removing salvage timber in a timely manner after large scale forest fires, while considering economic, environmental, and social (i.e. employment condition) constraints. For this purpose, a Post-fire Action Planning (PFAP) model was developed based on operational planning approach. Figure 4 indicates methodology of PFAP model.

In order to develop an objective function that minimizes total time spent on work stages of post-fire salvage logging operation, each work stage was evaluated separately. Thus, objective function aims to minimize total time spent on damage assessment (*DA*), felling (*F*), timber extraction (*TE*), hauling (*H*), and road construction (*RC*). The effects of different forest compartments (*c*), seasons (i.e. high density and low density seasons) (*s*), and alternative forest operation techniques (*t*), and damage assessment groups (*g*) were evaluated in solution process. Following equations indicates the objective function:

DA_{cs} = Damage assessment time per unit area (min/ha) per hectare by group “*g*”, at “*c*” compartment, during “*s*” season

A_{cst} = Fire damaged area (ha) at “*c*” compartment during “*s*” season

F_{cst} = Felling time per unit volume (min/m^3) at “*c*” compartment during “*s*” season by using “*t*” forest operation technique

V_{cst} = Volume of fire damaged timber (m^3) at “*c*” compartment during “*s*” season by using “*t*” forest operation technique

TE_{cst} = Timber extraction time per unit volume (min/m^3) at “*c*” compartment during “*s*” season by using “*t*” forest operation technique

H_{cst} = Hauling time per unit volume (min/m^3) at “*c*” compartment during “*s*” season by using “*t*” forest operation technique

RC_{cst} = Road construction time per unit length (min/m) at “*c*” compartment during “*s*” season by using “*t*” forest operation technique

L_{cst} = Road length constructed (meters) at “*c*” compartment during “*s*” season by using “*t*” forest operation technique

The constraints of the mathematical model are listed below:

1) The volume of extracted timber (TY_{cst}) from each forest compartments is limited to extraordinary timber yield of the compartments ($EXTY_{cst}$):

$$\sum_s^2 \sum_t^{72} W_{cst} \cdot TY_{cst} - EXTY_{cst} = 0$$

where W_{cst} = 1 if damaged timbers are extracted, or it is equal to “0” otherwise

2) The volume of total extracted timber from the study area after fire is limited to total extraordinary timber yield ($TEXTY_{cst}$):

$$\sum_c^{20} W_{cst} \cdot TY_{cst} - TEXTY_{cst} = 0$$

3) Each forest compartment damaged by fire must be subject to timber extraction:

$$\sum_s^2 \sum_t^{72} W_{cst} \cdot TY_{cst} \geq 1$$

Table 3. Alternative forest operation techniques used during work stages of post-fire salvage logging operation
Tablica 3. Alternativne tehnike šumskih radova korištenih tijekom radnih faza sječe šume nakon požara

Felling *Rušenje*	Timber Extraction *Privlačenje debla*	Hauling *Prijevoz*	Road Building *Izgradnja ceste*
Harvester	Manpower + Animal Power (MP+AP) *Ljudska snaga + životinjska snaga (LS+ŽS)*	Truck *Kamion*	Excavator *Bager*
Motor Manual[1] *Motorno ručno*	Manpower + Agricultural Tractors (MP+AT) *Ljudska snaga + poljoprivredni traktor (LS+PT)*	Tractor-trailer *Traktorprikolica*	Bulldozer *Buldožer*
Motor-Motor[2]	Manpower + Forest tractors (MP+FT) *Ljudska snaga + šumski traktor (LS+ŠT)*		
Motorno-Motorno[2]	Manpower + Skyline (MP+S) *Ljudska snaga + žičara (LS+Ž)*		
	Manpower + Skyline + Animal Power (MP+S+AP) *Ljudska snaga + žičara + životinjska snaga (LS+Ž+ŽS)*		
	Manpower + Chutes (MP+C) *Ljudska snaga + žlijebovi (LS+Žl)*		

[1] Felling is done by chainsaw and delimbing was done by axe
[1] Sječa se vrši motornom pilom, a obrezivanje grana vrši se sjekirom

[2] Felling and delimbing was done by chainsaw
[2] Sječa i obrezivanje grana vrše se motornom pilom

4) Timber extraction must be completed within 60 days (i.e. 28800 scheduled working minutes) after standing timber sale was done:

$$\sum_{s}^{2}\sum_{t}^{72} P_{cst}\cdot TY_{cst} \leq 28800$$

where P_{cst} is production rate (min/m^3) of forest operation technique.

5) In each forest compartments, timber extraction must be completed within 17 days (i.e. 8160 scheduled working minutes) of expected insect attacking time

$$\sum_{c}^{20} P_{cst}\cdot TY_{cst} \leq 8160$$

The mathematical model was developed based on linear programing because there is a linear relationship between model components (i.e. decision variables, objective function). Based on the site conditions, stand characteristics, and topographical features in the study area, several alternative forest operation techniques were evaluated for each work stages of post-fire salvage logging operation (Table 3). Analytical Hierarchy Process (AHP) was used to evaluate these techniques based on ecologic, economic, and social criteria (Table 4).

Table 4. Three main criteria considered in AHP application
Tablica 3. Tri glavna kriterija razmatrana u primjeni AHP

Criteria *Kriteriji*	Indicators *Indikatori*
Ecologic *Ekološki*	Soil disturbance – *Gaženje tla* Stand damage – *Šteta na sastojini*
Economic *Ekonomski*	Productivity – *Produktivnost* Cost – *Troškovi* Attainability – *Ostvarenje*
Social *Socijalni*	Suitability to regional development *Podobnost regionalnom razvoju* Workers health and safety – *Zdravlje i sigurnost radnika* Easy to implement – *Laka implementacija*

The planning purposes, regional suitability, time study analysis, and general information about alternative forest operation techniques were used to assign values to each criterion. The weighted values (1-very low priority; 2-low priority; 3- normal priority; 4-high priority; 5-very high priority) for each technique was assigned based on the indicators and then comparison matrixes were developed accordingly. Table 5 indicates sample comparison matrix for forest operation techniques used in timber extraction activities.

The output values of comparison matrixes were normalized and vectors of relative measures were generated. Then, constraints were produced based on these values and coefficients for the techniques were generated based on each indicator. Finally, coefficient of the each criterion was determined by adding coefficients of the indicators. MS Excel program was used to make the data ready for time study analysis. Then, the outputs generated by this analysis were reorganized to be used in LINDO program (Figure 5).

2.4. Post-fire Action Planning (PFAP) model – *2.4. Model planiranja aktivnosti nakon požara*

In order to minimize total time spent on post-fire salvage logging operation, multi matrix model was developed based on the forest compartments, alternative forest operation techniques, damage assessment groups, and seasons. Total of 20 forest compartments were evaluated in burned areas

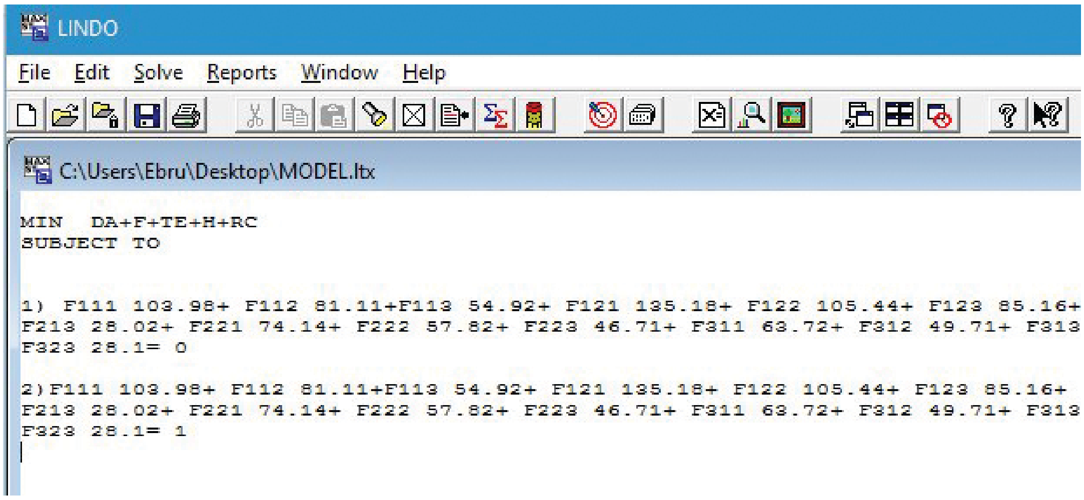

Figure 5. Mathematical functions coded in LINDO program
Slika 5. Matematičke funkcije kodirane u programu LINDO

Table 5. Comparison Matrix for techniques used in timber extraction
Tablica 5. Usporedna matrica za tehnike korištene u privlačenju drva

	MP+AP	MAP+AT	MP+FT	MP+S	MP+S+AP	MP+C
MP+AP	1.0	1.25	1.25	2.5	2.5	1.67
MAP+AT	0.8	1.00	1.00	2.0	2.0	1.33
MP+FT	0.8	1.00	1.00	2.0	2.0	1.33
MP+S	0.4	0.50	0.50	1.0	1.0	0.67
MP+S+AP	0.4	0.50	0.50	1.0	1.0	0.67
MP+C	0.6	0.75	0.75	1.5	1.5	1.00

Table 6. The size of solution space in three scenarios
Tablica 6. Veličina područja rješenja u tri scenarija

Scenarios *Scenariji*	Number of Compartments *Broj odjeljaka*	DA_g	C_t	TE_t	H_t	RC_t	Alternative Solutions *Alternativna rješenja*
I	20	3	3	6	2	2	4320
II	20	3	3	6	–	–	1080
III	6	3	3	6	2	2	1296

based on size and severity of the damage. In the model application, three felling techniques, six timber extraction techniques, two timber hauling techniques, and two road construction techniques were evaluated (Table 2). Thus, total of 72 logging system combinations were considered from felling to road construction activities. Besides, fire damage assessment activities were done by three groups with different number of team members (i.e. 2, 4, and 8 members). The performances of each group as also examined in the model.

Seasons were divided into two groups (high density and low density) based on fire frequency which was determined by analyzing fire statistics data obtained from fire headquarters in the study area. By considering different timber production and sale activities that were actually taken place in the study area after Serik-Taşağıl fire, three scenarios were evaluated and tested for each season during the solution process.

In the Scenarios I, three damage assessment groups (DA_g), three felling techniques (F_t), six timber extraction techniques (TE_t), two timber hauling techniques (H_t), and two road construction techniques (RC_t) were evaluated to find the optimum logging system combination with minimum operation time for 20 forest components. Thus, optimum solution with shortest salvage logging time was searched through 4320 alternative logging systems (Table 6). The model considers the stand characteristics of the forest compartments, terrain conditions, as well as economic, environmental, and social constraints. Based on the actual salvage logging implementations in the study area, new road sections were built in six forest compartments where road density was not sufficient (i.e. average 9.93 m/ha) for logging operations. It was also reported that forest products were sold at the landing areas in 11 forest compartments.

In the Scenario II, it was assumed that forest products were sold at the landing areas in all of the forest compartments. The objective function was developed without considering hauling and road construction techniques. Thus, it was aimed to minimize the time spent on post-fire salvage logging operations by considering 20 forest components, three damage assessment groups, three felling techniques, and six timber extraction techniques. The optimum solution with shortest salvage logging time was searched through 1080 alternative logging systems.

In the Scenario III, optimum logging system combination with minimum operation time was searched for six forest compartments that required new road sections in the study area. Thus, the effects of road construction on total time of salvage logging operation were analyzed. In the model, three damage assessment groups, three felling techniques, six timber extraction techniques, two timber hauling techniques, and two road construction techniques were evaluated. The optimum solution with shortest salvage logging time was searched through 1296 alternative logging systems.

3. RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The time spent on post-fire salvage logging operation could be minimized by using multi matrix model based on the alternative forest operation techniques, damage assessment, and seasons, while considering ecologic, economic, and social (i.e. employment condition) constraints. The effect coefficients of these constraints for operation time were determined based on multi-criteria analysis. The effect coefficient for felling time indicated that possibility of using harvester potentially reduces felling time but it was not a cost efficient alternative (Table 7).

Table 7. The effect coefficients for operation time
Tablica 7. Koeficijent učinka vremena rada

Forest Operations *Šumski radovi*	Ecologic *Ekološki*	Economic *Ekonomski*	Social *Socijalni*	Average *Prosjek*
Felling *Rušenje*				
Harvester	0.22	0.50	0.18	0.30
Motor-manual *Motorno-ručno*	0.44	0.20	0.46	0.37
Motor-motor *Motorno-motorno*	0.33	0.30	0.36	0.33
Timber Extraction *Privlačenje drva*				
MP+AP	0.24	0.18	0.24	0.24
MAP+AT	0.20	0.15	0.19	0.19
MP+FT	0.22	0.17	0.18	0.18
MP+S	0.10	0.15	0.11	0.11
MP+S+AP	0.15	0.15	0.15	0.15
MP+C	0.10	0.20	0.13	0.13
Hauling *Prijevoz*				
Truck *Kamion*	0.37	0.44	0.56	0.46
Tractor-trailer *Traktor-prikolica*	0.63	0.56	0.44	0.54
Road Construction *Izgradnja ceste*				
Excavator *Bager*	0.6	0.37	0.37	0.45
Bulldozer *Buldožer*	0.4	0.63	0.63	0.55

In Turkey, mechanized harvesting systems using harvester, feller-buncher, etc. can be very expensive, since machinery has high initial purchase prices and operating cost, which is correlated with very high fuel prices (Akay and Sessions, 2004). It was found that harvester minimized the time of felling activities in the both scenarios. The average felling time of harvester was 48.15 min per unit volume (m^3). On

Table 8. Time spent on forest operations and damage assessment in high density season
Tablica 8. Vrijeme provedeno u šumskim radovima i procjeni štete u sezoni velike gustoće

Activities *Aktivnosti*	Scenario I *Scenarij I*		Scenario II *Scenarij II*		Scenario III *Scenarij III*	
	(min/m^3)	(%)	(min/m^3)	(%)	(min/m^3)	(%)
Damage Assessment *Procjena štete*	614.65	23.05	614.65	24.16	195.86	26.38
Felling *Rušenje*	963.13	36.12	963.13	37.85	294.04	39.61
Timber Extraction *Privlačenje drva*	966.77	36.26	966.77	37.99	221.82	29.88
Hauling *Prijevoz*	114.40	4.29	–	–	23.19	3.12
Road Construction *Izgradnja ceste*	7.46	0.28	–	–	7.46	1.00
Total *Ukupno*	2666.41	100.00	2544.55	100.00	742.37	100.00

Table 9. Time spent on forest operations and damage assessment in low density season
Tablica 9. Vrijeme provedeno u šumskim radovima i procjeni štete u sezoni male gustoće

Activities *Aktivnosti*	Scenario I *Scenarij I*		Scenario II *Scenarij I*		Scenario III *Scenarij I*	
	(min/m^3)	(%)	(min/m^3)	(%)	(min/m^3)	(%)
Damage Assessment *Procjena štete*	942.97	26.17	942.97	27.32	252.88	26.28
Felling *Rušenje*	1252.06	34.75	1252.06	36.27	382.24	39.72
Timber Extraction *Privlačenje drva*	1256.80	34.88	1256.80	36.41	288.37	29.97
Hauling *Prijevoz*	141.77	3.93	–	–	29.11	3.03
Road Construction *Izgradnja ceste*	9.68	0.27	–	–	9.68	1.01
Total *Ukupno*	3603.28	100.00	3451.83	100.00	962.28	100.00

Table 10. Time spent on salvage logging operations in each forest compartment
Tablica 10. Vrijeme provedeno u sanacijskoj sječi u svakom šumskom odjeljku

No *Br.*	Forest Compartments *Šumski odjeljci*	Actual salvage logging time (day) *Stvarno vrijeme sanacijske sječe (dan)*	Salvage logging time found by the model (day) *Vrijeme sanacijske sječe u modelu (dan)*	Time reduced by the model (day) *Smanjeno vrijeme pomoću modela (dan)*
1	277	90	32.38	57.62
2	278	90	28.65	61.35
3	279	90	14.75	75.25
4	280	90	17.47	72.53
5	308	90	49.22	40.78
6	310	106	86.76	19.24
7	312	106	60.98	45.02
8	313	106	44.34	61.66
9	314	61	43.01	17.99
10	315	90	49.55	40.45
11	316	90	27.86	62.14
12	317	90	35.07	54.93
13	318	90	45.12	44.88
14	319	90	30.46	59.54
15	320	90	23.25	66.75
16	321	90	23.76	66.24
17	358	90	43.17	46.83
18	360	90	17.75	72.25
19	371	90	21.10	68.90
20	372	90	25.07	64.93
	Total	1819	719.72	1099.28

the other hand, motor-manual technique provided better solution in terms of economic aspects, while it potentially increases the felling time (Acar et al., 2003).

Based on the evaluation of timber extraction techniques, it was found that MP+AP technique tends to increase the timber extraction time. The results also indicated that MP+S technique reduces the timber extraction time, while satisfying ecologic, economic, and social constraints. In a sample forest component (Compartment 6) with the highest amount of timber extraction yield, it was found that MP+S technique minimized the logging time with 58.93 min/m^3, while timber extraction time was maximized using MP+AP technique (285.25 min/m^3). Skyline systems are more productive especially in mountainous areas with steep terrains (Demir and Bilici, 2010)

The effect coefficient for hauling time indicated that using logging trucks potentially reduces hauling time comparing with tractor-trailer hauling. Besides, logging trucks were better alternative in terms of ecologic and economic aspects. On the other hand, tractor-trailers were found to be socially efficient technique.

When analyzing road construction techniques, it was found that using bulldozer reduce operation time, while excavator provides better solution in terms of economic and social aspects (Öztürk et al., 2010). The fire damage assessment activities by three groups (i.e. 2, 4, and 8 members) were analyzed and results indicated that damage assessment time was 1.2 days for 10 hectares of forest fire. It was found that the group of 8 members minimized the damage assessment time in both scenarios.

The optimum combination of forest operation techniques and damage assessment methods were determined for three scenarios within two seasons. In the high density season, it was found that total times of optimum combinations were 2666.41, 2544.55, and 742.37 minutes for Scenario I, II, and III, respectively (Table 8). The most time consuming activity was timber extraction for Scenarios I (36.26%) and Scenario II (37.99%). The second time consuming activity was felling for both these scenarios. For Scenario III, felling was the most time consuming activity (39.61%), followed by timber extraction (29.88 %).

In the low density season, it was found that total times of optimum combinations were 3603.28, 3451.83, and 962.28 minutes for Scenario I, II, and III, respectively (Table 9). The most time consuming activity was again timber extraction for Scenarios I (36.26%) and Scenario II (37.99%), and followed by felling for both these scenarios. For Scenario III, felling was the most time consuming activity (39.72%), and again followed by timber extraction (29.97%).

The time spent on removing fire damaged timber was computed by the model for each forest compartment in the study area. Then, these results from the model were compared with time spent on the actual salvage logging operation taken place in high density season in the field (Table 10). The results indicated that using PFAP model capable of reducing total time of salvage logging operation from 1819 days to 720 days. This suggested that the model can save about 1099 days of operation time (60%) in the field. The difference between model and actual operation ranged from 17.99 days (9^{th} compartment) to 75.25 days (3^{rd} compartment). It was also found that using PFAP model potentially provides optimum solutions in terms of both ecological and economic aspects.

4. CONCLUSIONS
4. ZAKLJUČCI

The forest fire is one of the most detrimental natural disasters that damage forest ecosystem, threat human life, and cause important economic losses. Therefore, forest operation activities should be immediately planned and implemented after forest fires to restore and maintain forest ecosystem in burned areas. Planning of post-fire salvage logging operations involve many stages, decision variables, and constraints that require operational planning approach and multi-criteria decision-making process. In this study, a Post-fire Action Planning (PFAP) model was developed to minimize the total time spent on post-fire salvage logging activities. PFAP model is capable of evaluating and planning many work stages of salvage logging operations, while considering ecological, economic, and social constraints. In order to properly manage chaotic circumstances after forest fires and to ensure sustainable management of forest resources at the same time, operational planning based PFAP model assists decision makers for quick and effective planning of salvage logging operations. Besides, this model can be used to assess necessary workforce, forest operation techniques, and financial conditions prior to any forest fires so that limited sources and time can be managed properly for actual fire incidents.

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REFERENCES
LITERATURA

- Acar, H.H., Eker, M., Eroğlu, H. 2003. A review on the wood harvesting and transportation technologies in Turkish forestry. XII World Forestry Congress, 21-28 September, Quebec, Canada.
- Akay, A.E., Sessions, J., 2004. Identifying the Factors Influencing the Cost of Mechanized Harvesting Equipment. KSU. Journal of Science and Engineering 7(2):65-72.
- Akay, A.E., Sessions, J., Bettinger, P., Toupin, R., Eklund, A., 2006. Evaluating the salvage value of fire-killed timber by helicopter-effects of time since fire and yarding distance, Western Journal of Applied Forestry, 21(2): 102-107.
- Akay, A.E., Erdas, O., Kanat, M., Tutus, A., 2007. Post-fire salvage logging for fire-killed brutian pine (*Pinus brutia*) trees. Journal of Applied Sciences 7(3):402-406.
- Akay, A.E., 2009. The effects of Forest harvesting techniques on optimum bucking application of oriental spruce (*Picea orientalis*) stands in Turkey. Austrian Journal of Forest Science. 127(1): 25-36.
- Andersson, D., Eriksson, L.O., 2007. Effects of temporal aggregation in integrated strategic/tactical and strategic forest planning. Forest Policy Econ. 9 (8): 965-981.
- Bilici, E., 2009. A study on the integration of firebreaks and fireline with forest roads networks and it's planning and construction (A Case Study of Gallipoly National Park) Istanbul University. Faculty of Forestry Journal Series: A. 59(2): 86-102.

- Demir, M., Bilici, E., 2010. Assessment of timber harvesting mechanization level in Turkey, FORMEC 2010: Forest Engineering: Meeting the Needs of the Society and the Environment, 11-14 July, Padova, Italy.
- Drosos, V.C., Farmakis, D.E., Kalogeropoulo, C.P., 2008. Digital Terrain Model geoinformatic Model-Harvesting operations after fires, FORMEC 08-KWF, 2-5 June, Schmallenberg, Germany.
- Eker, M., 2004. Development of annual operational planning model for timber harvesting. Ph.D. thesis. Karadeniz Technical University, Trabzon. 239 p.
- Eker, M., Çoban, H.O., 2009. Post-fire harvesting and transportation model, The First Forest Fire Fighting Symposium, 07-10 January, Antalya, Turkey. p: 395-403.
- Çoban, H.O., Eker, M., 2010. Analysis of forest road network conditions before and after forest fire, FORMEC 2010: Forest Engineering: Meeting the Needs of the Society and the Environment, 11-14 July, Padova, Italy.
- GDF, 2008. Rehabilitation of burnt forest Areas and a fireproof forest facility project report. GDF publications, Antalya, Turkey. 112 p.
- Guido, R., Van derr Werf, J.T., Randerson, G., James Collatz, L., Giglio, P.S., Kasibhatla, A.F., 2004. Continental-scale partitioning of fire emissions during the 1997–2001 El Nino/La Nina period. Science, 303: 73-76.
- Kaloudis, S., Costopoulou, C.I., Lorentzos, N.A., Sideridis, A.B., Karteris, M., 2008. Design of forest management planning DSS for wildfire risk reduction. Ecol. Inf. 3 (1).122–133.
- Karantzidis, N., Mpasianas, G., Doukas, K., 2008. Forest constructions for protection and harvesting operations before and after forest fires in Greece, FORMEC 08-KWF: 2-5 June, Schmallenberg, Germany.
- LINDO, 2010. Available at: www.lindo.com [Last accessed 13 October 2016].
- Reynolds, K.M., 2005. Integrated decision support for sustainable forest management in the United States: fact or fiction? Comput. Electron. Agric. 49 (1):6–23.
- Saaty, T.L., 1980. The Analytic Hierarchy Process. McGraw-Hill, New York.
- Öztürk, T., İnan, M., Akay, A.E., 2010. Analysis of tree damage caused by excavated materials at forest road construction in Karst Region, Croatian Journal of Forest Engineering. 31: 57-64.
- Öztürk, T., Hasdemir, M., Şentürk, N., 2011. The potential usage of modern logging machines for extraction of post-fire salvage timber, The First Mediterranean Forest and Environment Symposium, 26-28 October, Kahramanmaraş, Turkey.
- Zeng, H., Pukkala, T., Peltola, H., 2007a. The use of heuristic optimization in risk management of wind damage in forest planning. For. Ecol. Manage. 241:189–199.

Sažetak

Nakon šumskih požara nastaju različiti problemi, kao što je velik gubitak drvne mase, erozije tla, degradacija pitkih izvora vode te onečišćenje zraka. Neophodno je kvalitetno i učinkovito isplanirati i implementirati potrebne šumske operacije nakon šumskog požara, kako bi se odmah moglo započeti s pošumljavanjem u svrhu održanja šumske vegetacije u izgorenim područjima. Cilj ovoga istraživanja je bio razvoj modela planiranja aktivnosti nakon požara, kako bi se smanjilo vrijeme utrošeno na aktivnosti sanitarne sječe. Model planiranja aktivnosti nakon požara pomoći će donositeljima odluka u pravovremenom uklanjanju saniranih debla nakon velikih šumskih požara, uzimajući u obzir ekonomska i ekološka ograničenja te rješavajući mogućnost zapošljavanja u lokalnoj drvnoj industriji. Mogućnosti ovoga modela provjerene su pomoću standardizacije operativnog planiranja i razvoja procesa brzog donošenja odluka. Model je implementiran u šumariji Taşağıl Regionalne uprave za šume Antalya, gdje su šume svrstane u prvi stupanj opasnosti od požara te se drugi najveći šumski požar u povijesti Turske uprave za šume dogodio upravo na ovome području 2008. godine. Rezultati ovoga modela uspoređeni su s podatcima stvarnih sanacijskih sječa dobivenih od šumarija. Rezultati su pokazali da se korištenjem operativnog planiranja temeljem modela planiranja aktivnosti nakon požara može smanjiti ukupno vrijeme utrošeno na sanacijske sječe za 60%. S obzirom na različite šumske odjeljke u istraživanome području, procijenjeno trajanje sanacijske sječe bilo je 15 do 75 dana kraće od stvarnih operacija na terenu. Prema tome, očekuje se da korištenje operativnog planiranja temeljem modela planiranja aktivnosti nakon požara ima velik potencijal u osiguravanju ekonomski i ekološki korisnih šumskih radova nakon šumskih požara.

KLJUČNE RIJEČI: šumski požar, sanacijska sječa, šumski prijevoz, operativno planiranja, modeliranje