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Developing GIS based Decision Support System for Planning Transportation of Forest Products

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Abstract

Transportation of forest products is a complex problem that requires evaluation of many alternative routes. This indicates the necessity of using computer-assisted methods in planning transportation of forest products and systematically searching for the optimum route. In this study, Geographical Information System (GIS) based decision support system was used to decide the optimum route which minimizes the transportation cost of various forest products (i.e. logs, industrial wood, paper, mine pole). The study area was implemented in Mustafakemalpaşa Forest Enterprise Directorate (FED) located in the city of Bursa. There were three Forest Enterprise Chiefs (Paşalar, Sarnıç, Turfal) and five forest depots in the study area. Three depots were in Paşalar Forest Enterprise Chief (FEC), while the other FECs had one depot each. The optimum routes, providing the most economic transportation from temporary timber bunching areas (total of 41 areas) at the forest to forest depots, were determined by using Network Analyst extension of ArGIS 10.2 program. Also, the road sections located in inaccessible areas under landslide risk were disregarded during network analysis for safety purposes. In the solution process, two scenarios were applied: 1) the forest products extracted from a FEC were only transported to the depot(s) of that FEC, and 2) the forest products extracted from any FEC were transported to any of the depots in the study area. The results indicated that the total transportation cost was 88424 TL in the first scenario, while it was dropped to 88161 TL in the second scenario. It was found that transportation cost was relatively low in the FECs with more than one forest depots. The other important factor that affects the cost was the distance between temporary timber bunching areas and forest depots.

Keywords: Forest transportation, GIS, Network analysis, Shortest path

1. Introduction

The extraction of forest products is a very complex problem that requires effective planning and implementation of various activities including timber harvesting, hauling timber from forest sites to temporary timber bunching areas, and forest transportation [1]. Among these activities, one of the most costly stages is the forest transportation in which forest products are hauled from temporary timber bunching areas to forest depots [2]. The previous studies indicated that the cost of forest transportation is about 40% of total timber production costs. Thus, developing optimum transportation of forest products is critical to minimize overall cost of timber production in Turkey [3].

The transportation of forest products has been done by using specially manufactured logging trucks. The hourly cost of logging trucks, average truck speed, and load capacity are the main factors that affect transportation costs. Besides road slope, road length, road type, and road condition are the other factors that affect transportation costs. In order to improve productivity of transportation activity, hauling time should be minimized by using the shortest path (i.e. route with minimum travel time) from bunching areas to forest depots. Besides, improving the road standards will allow logging trucks to travel at a higher speed which will also reduce the hauling time.

Traditional forest transportation plans generally depend on experiences of forest mangers which are not capable of determining optimum solution among many alternatives. Thus, computer-based models can be utilized for developing optimum transportation plans that will save time and money [4]. The network analysis, linear programming, dynamic programming, and heuristic techniques have been used to develop

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such models [5]. The network analysis based models has been effectively used to find the shortest route, the path with minimum transportation cost, optimum project, and maximum flow of values [6]. In recent years, Geographical Information System (GIS) based decision support systems using network analysis method have been implemented for solving vehicle routing problems [7, 8].

In this study, GIS-based decision support system utilizing network analysis method was used to develop an optimum forest transportation plan which minimizes the transportation cost and ensures a safe travel. In the solution process, the optimum route for transportation of various forest products from temporary timber bunching areas to forest depots was systematically searched by using Network Analyst extension in ArcGIS 10.2 program. The road sections located in areas with landslide risks were excluded during the network analysis to provide the safest route for truck traveling.

2. Material and Methods

2.1. Study Area

The study area was within the borders of Paşalar, Sarnıç, and Turfal FECs in Mustafakemalpaşa FED located in the city of Bursa (Figure 1). The information about timber extraction locations and temporary timber bunching areas (total of 41) was obtained from FED. The areal distribution of forest resources in Mustafakemalpaşa FED was indicated in Table 1. In the study area, the dominant tree species are beech, oak, fir, Brutian pine, Stone pine, and Maritime pine.

Figure 1. Study area

Table 1. The areal distribution of forests in (ha) [9]

FEC	High Forest	Degraded Forest	Total Forest
Burhandağ	6794. 0	3513.40	10312.50
Çaltılıbük	9900.50	3553.90	13454.40
Devecikonak	8337.40	4290.20	12627.60
Gürgendağ	6106.00	1050.20	7156.20
Karacabey	5256.30	7751.30	13003.10
M.K.paşa	10525.60	5329.30	16 55.40
Paşalar	3423.50	1596.30	10020.30
Sarnıç	4094.60	303. 0	4903.20
Turfal	5624.50	313.00	6442.50
Yeniköy	7922.60	1092.30	9015.40
Karadağ	7703.70	1397.40	9606.10
TOTAL	80693.80	32207.90	112901.70

There are five forest depots within the border of studying area (Table 2). The forest products extracted from a FEC are transported to the depot(s) of that FEC as a common practice. However, the forest products extracted from any FEC can be transported to the depots of neighboring FECs based on an agreement [10].

Table 2. Forest depots in the study area

Depots	FECS
Sarnıç	Sarnıç
Paşalar	Paşalar
Sünlük	Paşalar
Karapınar	Paşalar
Karaorman	Turfal

The forest depots were visited and information about the production types (i.e. log, mine pole, industrial round wood, and paper wood) were recorded. The volume of forest products, associated harvesting compartments, and tree species were listed in Table 3, 4, and 5.

Table 3. The forest products in Sarnıç FEC (m^3)

Compartment	Log		Industrial Wood		Paper wood
	Oak	Beech	Oak	Beech	Beech
70	-	108.53	29.76	39.13	29.01
71	22.2	-	60.37	59.29	10.7
80	-	1395.43	-	272.92	177.29
93	-	683.61	-	300.11	143.66
95	-	1350.43	-	250.98	138.86
96	-	1046.36	-	309.02	158.11
97	-	74.39	-	-	-
104	-	524.5	-	94.06	49.85
105	-	913.4	-	166.04	121.9
109	-	859.05	-	117.88	103.94
112	-	205.91	-	28.89	25.94
115	-	477.74	-	124.02	101.01
118	-	133.3	-	25.94	-
Total	22.2	7772.65	90.13	1788.28	1060.27

Table 4. The forest products in Paşalar FEC (m^3)

Compartment	Log			Mine Pole	Industrial Wood	Paper Wood
	Oak	Beech	Fir	Beech	Beech	Beech
116	-	527.23	-	-	156.86	52.14
118	48.83	344.8	-	24.85	88.89	59.49
137	-	895.4	-	-	148.77	63.66
143	-	283.38	-	-	69	138.22
151	-	545.93	-	21.35	61.77	37.02
152	-	413.6	-	24.95	72.41	28.07
163	-	153.7	-	-	46.72	-
171	-	91.21	-	-	-	25.48
188	-	42.52	42.52	-	-	-
194	-	25.91	-	-	-	-
220	-	28.53	-	-	-	-
224	-	83.41	-	-	-	-
230	-	100.67	-	-	-	-
Total	48.83	3536.29	42.52	71.15	644.42	404.08

Table 5. The forest products in Turfal FEC (m^3)

Compartment	Log	Industrial Wood	Paper Wood
	Beech	Beech	Beech
88	697.05	266.27	115.92
98	51.65	-	-
102	630.48	120.3	56.68
104	810.88	182.92	-
105	450.16	94.18	62.02
113	83.88	-	-
114	871.174	139.02	131.97
115	109.65	-	-
116	951.84	184.13	62.23
117	842.02	65.528	55.87
118	332.43	105.41	73.34
119	186.63	157.21	76.21
121	196.44	32.77	36.92
127	88.58	-	-
135	288.63	47.89	-
Total	5009.17	1395.63	671.16

2.2. GIS Database

A GIS database was generated based on topographical maps (1:25000), forest management maps (1:25000), coordinates of forest depots, and coordinates of temporary timber bunching areas. Then, ArcGIS 10.2 program was used to produce a road network map, map of depots, and map of bunching areas.

The truck travel time was computed based on the road length and average truck speed. The average truck speed varies depending on road type and conditions. Thus, specific data fields, including length (km), road type (asphalt, gravel, forest road), road conditions (good, average, and bad), truck speed (km/hr), and travel time (hours) were included into attribute table of the road map. The UTM coordinates of the depots and bunching areas were recorded by using hand GPS.

2.3. Network Analysis

Network Analyst extension of ArcGIS 10.2 can be used to determine the optimum route between two known points based on a network analysis approach. The network system is constructed by combining links (arcs) and intersection points of links (nodes) [11]. The value assigned to each link may include length, transportation cost, and travel time. The optimum route is selected by searching the route that minimizes the sum of the total link parameter values [12]. In this study, transportation cost was assigned to the links that represented the road sections in the network analysis database. The cost of each road link (TL/m3) was included into attribute table of the road map as a new field.

Based on the field trips and the data obtained from FED, the road conditions were determined considering road slope, road quality, and curves. Then, truck speed was estimated based on road type and road conditions [13, 14]. The average truck speed used in this study for various road types was listed in Table 6 [11].

Table 6. The average truck speed for road types and conditions (km/hr)

Road type	Road Condition		
	Good	Average	Bad
Asphalt	60	50	40
Gravel	40	30	20
Forest road	25	20	15

The transportation cost (TL/m3) was computed based on hourly cost of logging truck (TL/hr), load capacity (m3), and working time of truck (hr) [10]:

$$C_t = \frac{c}{\left(\frac{v}{t}\right)} \tag{1}$$

C_t = transportation cost
c = hourly cost of truck
v = load capacity
t = working time of truck

The hourly cost of logging truck and load capacity was obtained from FED as 46.86 TL/hr and 15 ton (m3), respectively. The working time of truck was computed by using the following formula [15]:

$$t = (1+d)2L/s \tag{2}$$

L = road length (km)
s = truck speed (km/hr)
d = delay time (%)

where delay times for each road link were 15%, 10%, and 5% for forest road, gravel road, and asphalt road, respectively [10].

2.4. Network Analyst

Network Analyst extension of ArcGIS 10.2 was used to find an optimum route with minimum transportation cost (Figure 2). The New Closest Facility method within the Network Analyst extension was implemented to explore optimum routing solutions for timber hauling to forest depots.

In the solution process, two scenarios were considered: 1) The forest products extracted from a FEC were only transported to the depot(s) of that FEC, and 2) The forest products extracted from any FEC were transported to any of the depots in the study area. Besides, the road sections with landslide risks were excluded from network analysis by locating barrier polygons to provide safe hauling route (Figure 3).

3. Results and Discussion

The results indicated that the total length of the road network in the study area was 519 km in which about 71% was forest road, while 18% and 11% were asphalt and gravel road, respectively. The road network map was indicated in Figure 4.

Five forest depots were evaluated during the network analysis application. Three of the depots were within the border of Paşalar FEC, while the other two FECs (i.e. Sarnıç and Turfal) had single depot. Forest products were transported from total of 41 temporary timber bunching areas to these five depots. There were 15 bunching areas in Turfal FEC, while both Paşalar and Sarnıç had 13 bunching areas. The locations of the depots and temporary timber bunching areas were indicated in Figure 5.

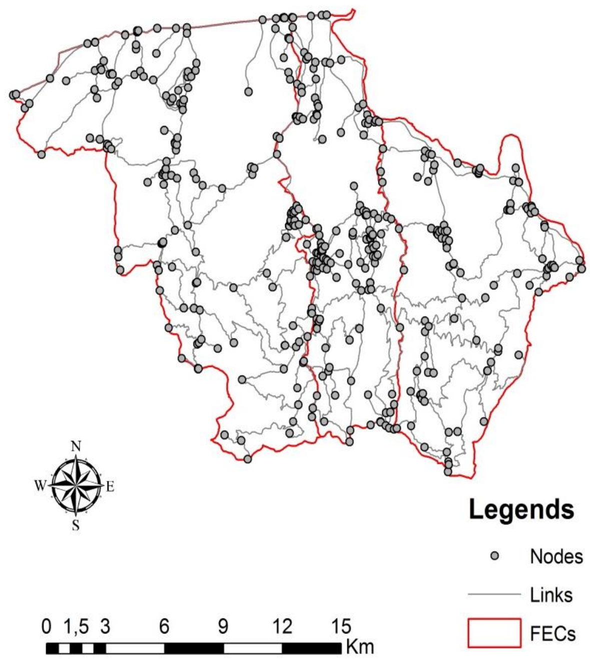

Figure 2. Road network

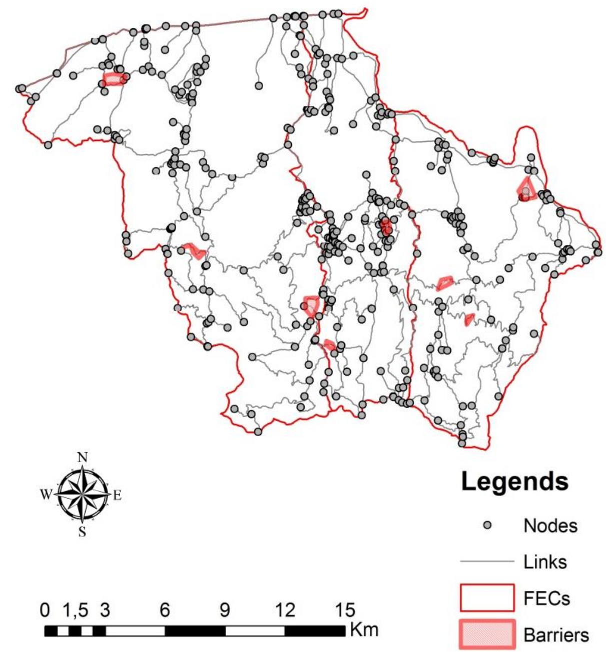

Figure 3. Barrier used to exclude some road sections

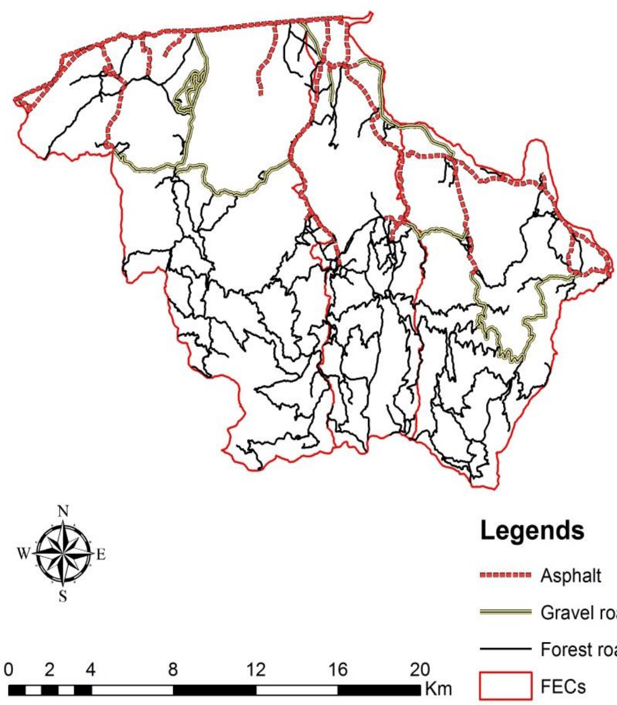

Figure 4. The road network map

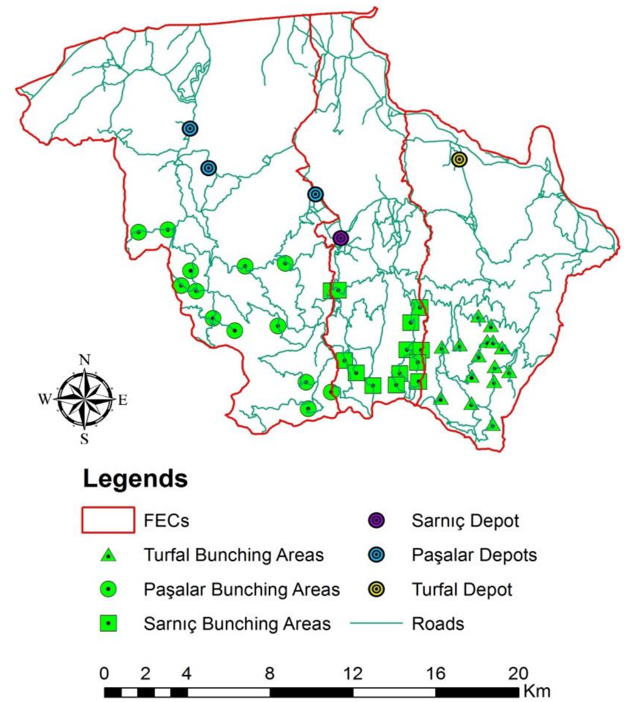

Figure 5. Forest depots and timber bunching areas

3.1. Scenario I

In the first scenario, the forest products extracted from a FEC were only transported to the depot(s) of that FEC. For Sarnıç FEC, 13 temporary timber bunching areas and a forest depot (Sarnıç) were evaluated in the forest transportation planning. Using New Closest Facility method, optimum routes that minimize the transportation costs from each bunching area to forest depot was determined (Figure 6). The total cost of transporting forest products to Sarnıç Depot was found to be about 34565 TL.

For Paşalar FEC, 13 temporary timber bunching areas and three forest depot (Paşalar, Sünlük, and Karapınar) were evaluated in the forest transportation planning. Using New Closest Facility method, optimum routes that minimize the transportation costs from each bunching area to forest depot was determined (Figure 7). The total costs of transporting forest products to Paşalar, Sünlük, and Karapınar Depots were found to be about 7967 TL, 3275 TL, and 5037 TL, respectively. It was found that the forest products from four timber bunching areas were transported to Paşalar Depot, while Sünlük and Karapınar depots received forest products from six and three bunching areas. The total cost of transporting forest products at Paşalar FEC was found to be about 16279 TL.

For Turfal FEC, 15 temporary timber bunching areas and a forest depot (Karaman) were evaluated in the forest transportation planning. The optimum routes that minimize the transportation costs from each bunching area to forest depot were determined using New Closest Facility method (Figure 8). The total cost of transporting forest products to Karaman Depot was found to be about 37580 TL.

When comparing the total transportation costs of FECs, it was found that the lowest total cost was in Paşalar FEC (Table 7). There were three forest depots which were close to forest harvesting areas. The cost was the highest in Turfal FEC where there was only one forest depot which was far away from the harvesting areas.

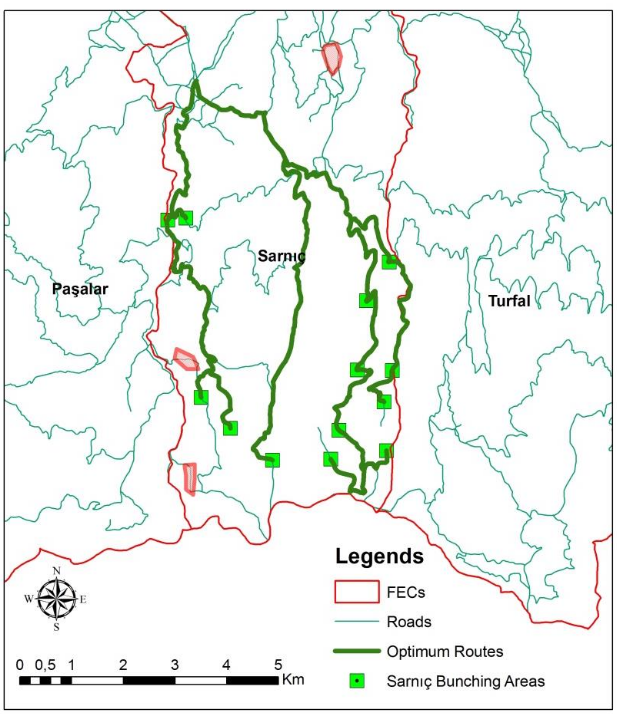

Figure 6. The optimum routes with minimum transportation cost in Sarnıç FEC

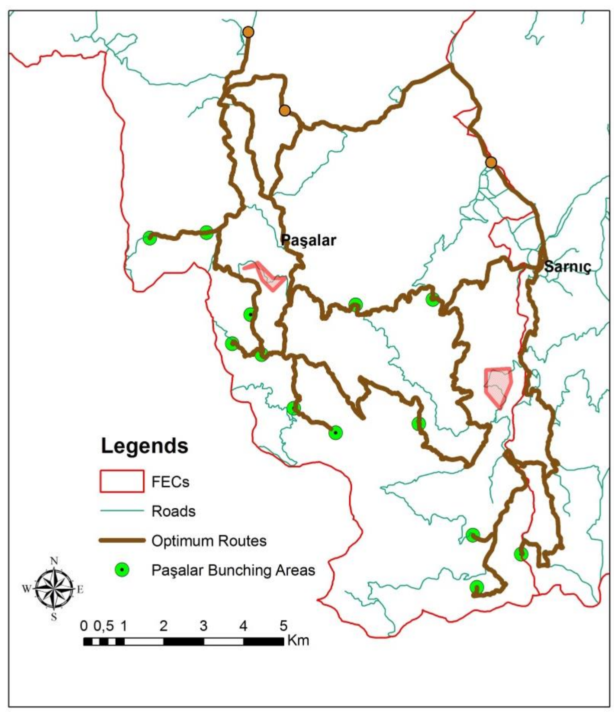

Figure 7. The optimum routes with minimum transportation cost in Paşalar FEC

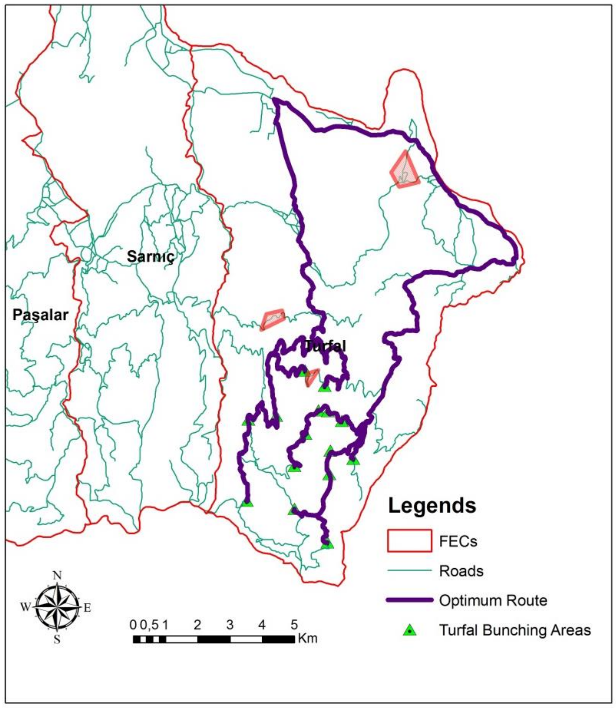

Figure 8. The optimum routes with minimum transportation cost in Turfal FEC

Table 7. Transportation costs regarding with forest depots

FECs	Forest Depots	Transportation Cost (TL)
Sarnıç	Sarnıç	34565
Paşalar	Paşalar	7967
Paşalar	Sünlük	3275
Paşalar	Karapınar	5037
Turfal	Karaorman	37580
	Total	88424

The transportation costs regarding with forest products were computed for FECs (Table 8). Log was the forest product with the highest transportation cost, followed by industrial wood, paper wood, and mine pole. The most important factor on the transportation cost was timber volume.

Table 8. Transportation cost regarding with forest products

FECs	Log	Industrial Wood	Paper Wood	Mine Pole
Sarnıç	25413.66	5741.05	3409.93	-
Paşalar	12673.09	2047.79	1327.25	231.12
Turfal	28961.23	5832.01	2787.08	-
Total	67047.98	13620.85	7524.26	231.12

3.2. Scenario II

In the second scenario, the forest products extracted from any FEC were transported to any of the depots in the study area (Figure 9). The optimum routes, providing the most economic transportation from temporary timber bunching areas (total of 41 areas) to forest depots, were determined using Network Analyst extension. The total cost was found to be about 88161TL.

In the second scenario, the lowest total cost was in Paşalar FEC while the highest in Turfal FEC (Table 9). On the other hand, the total transportation cost was reduced from 88424 TL to 88161 TL when making all forest depots available for extracted forest products in the study area. The reason behind this cost reduction was that some of the forest products extracted within the border of Paşalar FEC were directed to Sarnıç Forest Depot with a lower transportation cost.

Transportation costs regarding with forest products were computed for FECs (Table 10). Log was the forest product with the highest transportation cost, followed by industrial wood, paper wood, and mine pole. It was revealed that the transportation cost of log, industrial wood, and paper wood were reduced by 179 TL, 39 TL, and 46 TL, respectively.

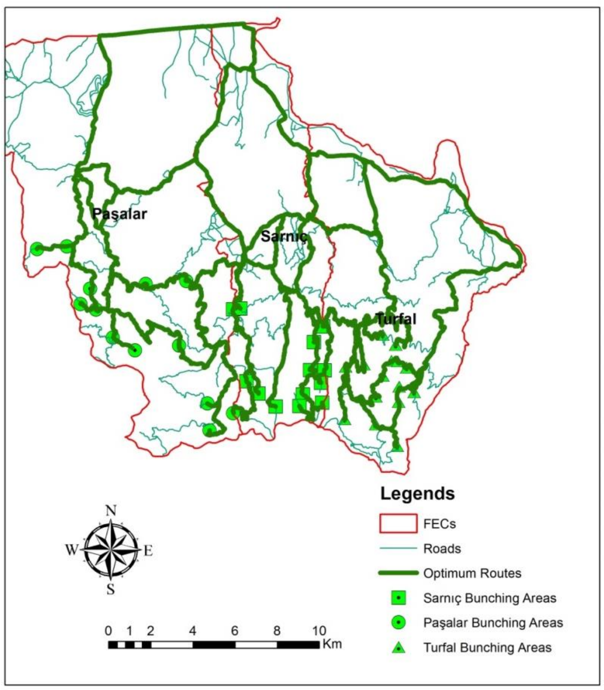

Figure 9. The optimum routes with minimum cost

Table 9. The transportation cost regarding with forest depots

FECs	Forest Depots	Transportation Cost (TL)
Sarnıç	Sarnıç	36856.83
Paşalar	Paşalar	7967.10
Paşalar	Sünlük	719.78
Paşalar	Karapınar	5037.15
Turfal	Karaorman	37580.33
	Total	88161.19

Table 10. The transportation cost regarding with forest products

FECS	Log	Industrial Wood	Paper Wood	Mine Pole
Sarnıç	27012.12	6025.64	3819.07	-
Paşalar	10895.86	1724.53	872.51	231.12
Turfal	28961.23	5832.01	2787.08	-
Total	66869.21	13582.18	7478.66	231.12

4. Conclusions

The optimum route for transportation of various forest products from temporary timber bunching areas to forest depots was systematically searched by using Network Analyst extension in ArcGIS 10.2 program. The road sections located in areas with landslide risks were not included into network analysis to ensure a safe travel for logging truck. The results revealed that alternative forest depots potentially reduce the transportation cost of forest products. Besides, the distance between forest depots and timber bunching areas significantly affects transportation cost. In the solution process, two scenarios were applied: 1) the forest products extracted from a FEC were only transported to the depot(s) of that FEC, and 2) the forest products extracted from any FEC were transported to any of the depots in the study area. It was found that the total transportation cost was reduced in the second scenario since the network analysis method evaluated all of the forest depots and found an optimum transportation with minimum costs. The methodology presented in this study can be implemented in any forested areas if the necessary digital data are available. The methodology can be improved in the future studies by considering the costs of timber extraction, logging, and loading activities. On the other hand, the effects of road standards on transportation costs should be evaluated through an extensive research project. The effects of alternative logging trucks with various sizes on transportation efficiency should also be investigated in the future works.

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References

[1] Erdaş, O. (1986). Selection of system in the stages of forest harvesting, logging, and transportation. Karadeniz Technical University, *Faculty of Forestry Journal*, 9(1-2):91-113.

[2] Acar, H.H., Eroğlu, H. (2001). The planning of wood transport on the forest roads. Kafkas University, *Faculty of Forestry Journal*, 61-66.

[3] Acar, H.H. (1998). Minimization to be using of transport model of transportation costs by trucks at Artvin Forest District. *Journal of Agriculture and Forestry*, 22: 491-497.

[4] Sessions, J., Chung W., Heinimann, H.R. (2001). New algorithms for solving large scale harvesting and transportation problems including environmental constraints. in Proc. of the FAO/ECE/ILO workshop on new trends in wood harvesting with cable systems for sustainable forest management in mountain forests, June 18-24, Ossiach, Austria.

[5] Akay, A.E., Wing, M.G., Sivrikaya, F., Sakar, D. (2012). A GIS-based decision support system for determining the shortest and safest route to forest fires: a case study in Mediterranean Region of Turkey. *Environ Monit Assess*, 184:1391-1407.

[6] Başkent, E.Z. (2004). Operations Research, Modelling and Natural Resource Applications. Karadeniz Technical University, Faculty of Forestry, General Publication No: 218, Faculty Publication No: 36. KTU Publishing. Trabzon. 480 p.

[7] Manussaridis, Z., Mamaloukas, Ch., Spartalis, S. (2007). A VRS dimension framework for effective DSS design. *Applied Mathematical Sciences,* 1(42):2079– 2090.

[8] Keenan, P. (2008). Modelling vehicle routing in GIS. Operational Research, 8(3):201–218.

[9] URL 1, (2015). Bursa Forest Regional Directorate. http://bursaobm.ogm.gov.tr [Accessed: 22 February 2017]

[10] Akay, A. E., Erdaş, O. (2007). Network Model approach in transportation planning of forest products. *Journal of the Faculty of Forestry Istanbul University*. 57(2):1-20.

[11] Akay, A.E., Şakar, D. (2009). Using GIS based decision supporting system in determining optimum path that provides the transportation to fire zone at the shorthest time. TMMOB Geographical Information Systems Congress, 02-06 Novermber. İzmir.

[12] Akay, A.E., Erdaş, O., Karaş, İ.R. (2006). Using GIS and optimization techniques in selecting forest road alignment with minimum sediment yield. 1st Remote Sensing-GIS Workshop, 27-29 November, İTÜ, İstanbul.

[13] Erdaş, O. (1997). Forest Roads. Volume I-II. K.T.U. Publication No:187. Trabzon. 744 p.

[14] Eroğlu, H., Özmen, T. (2010). A research on the logging operation with animal power in terms of productivity. III. National Blacksea Forestry Congress. 20-22 May, Artvin, 2: 554-563.

[15] Akay, A. E., Şakar, D. (2010). Planning transportation of forest products by using GIS based decision support system. III. National Blacksea Forestry Congress. 20-22 May, Artvin. 2: 504-513.