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Research Article

USING GIS-BASED DECISION SUPPORT SYSTEM FOR DETERMINING OPTIMUM ROUTING OF LOGGING TRUCKS

Abdullah E. Akay

Bursa Technical University, Faculty of Forestry, Dept. of Forest Engineering, Bursa, Turkey

ORCID ID: 0000-0001-6558-9029

*Corresponding Author: abdullah.akay@btu.edu.tr

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Abstract

Forest products are transported from landing areas to forest depots using logging trucks. Considerable amount of the total cost in the timber production in Turkey constitutes the costs of transporting forest products by logging trucks. Many alternative plans are evaluated using computer technology and optimization techniques to develop an optimum transportation planning. Network analysis, one of the operations research techniques, has been widely used to solve such transportation problems with various constraints. In recent years, computer-based techniques integrated with Geographic Information Systems (GIS) have been implemented to solve transportation problems. Network analysis-based modules of ArcGIS software such as "Network Analyst" can be also used to solve transport problems. In addition, factors that directly affect the transportation cost, such as truck size, can be evaluated in the solution process. In this study, "Network Analyst" module of ArcGIS 10.4 program was used to investigate the optimum transportation routes that minimize the total transportation cost of forest products considering three truck types. In the implementation of the system, road network data in İclaliye Forest Enterprise Chief (FEC) located in İnegöl Forest Enterprise Directorate (FED) was taken into consideration. In the model application, four forest harvesting units, three forest products (2nd quality Beech logs, 3rd quality Beech logs, and paperwood), three types of logging trucks (small, medium and large size) and a forest depot in İclaliye FEC were evaluated. The results of GIS-based decision support system showed that when using small, medium and large logging trucks, the total transportation cost was minimized at 16391 TRY (Turkish Lira), 14640 TRY and 10671 TRY, respectively. When using medium trucks instead of small trucks, the transportation cost of forest products decreased by 10.68% while the cost decreased by 34.90% when using large trucks. As a result, it was revealed that there is a close relationship between logging truck dimensions and transportation cost of forest products.

Keywords: Forest transportation; optimum hauling route; GIS; Network Analyst.

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Arastirma Makalesi

CBS TABANLI KARAR DESTEK SİSTEMİ İLE TOMRUK KAMYONLARININ OPTİMUM ROTASININ BELİRLENMESİ

Özet

Orman ürünleri, genellikle tomruk kamyonları kullanılarak rampa alanlarından orman depolarına taşınmaktadır. Türkiye'de orman ürünleri üretiminde toplam maliyetin önemli bir kısmını tomruk kamyonları ile gerçekleştirilen transport maliyeti oluşturmaktadır. Optimum transport planını geliştirmek için bilgisayar teknolojisi ve optimizasyon teknikleri kullanılarak birçok alternatif plan değerlendirilebilmektedir. Yöneylem araştırması tekniklerinden biri olan ağ analizi, çeşitli kısıtlamalar içeren bu tür ulaşım problemlerinin çözümünde yaygın olarak tercih edilmektedir. Son yıllarda, ulaşım problemlerini çözümünde Coğrafi Bilgi Sistemleri (CBS) ile entegre bilgisayar tabanlı teknikler uygulanmaktadır. ArcGIS yazılımının "Network Analyst" gibi ağ analizi tabanlı modülleri de ulaşım problemlerini çözmek için kullanılabilmektedir. Ayrıca, kamyon boyutu gibi transport maliyetini doğrudan etkileyen faktörler çözüm sürecinde değerlendirilebilmektedir. Bu çalışmada ArcGIS 10.4 programının "Network Analyst" modülü, üç kamyon tipi için orman ürünlerinin toplam transport maliyetini en aza indiren optimum nakliyat rotasının belirlenmesinde kullanılmıştır. Sistemin test edilmesinde, İnegöl Orman İşletme Müdürlüğü'ne bağlı İclaliye Orman İşletme Şefliği yol ağı verileri dikkate alınmıştır. Model uygulamasında, dört üretim sahası, üç orman ürünü (2. kalite Kayın tomruğu, 3. kalite Kayın tomruğu ve kağıtlık odun), farklı tonajda üç tip tomruk kamyonu (düşük, orta ve yüksek tonajlı) ve Orman İşletmesindeki orman deposu değerlendirilmiştir. CBS tabanlı karar destek sisteminin sonuçları, düşük, orta ve yüksek tonajlı tomruk kamyonları için toplam nakliye maliyetinin sırasıyla 16391 TL, 14640 TL ve 10671 TL olarak minimize edildiğini göstermiştir. Düşük tonajlı kamyonlar yerine orta tonajlı kamyonlar kullanıldığında, orman ürünlerinin transport maliyeti %10,68 azalırken, büyük tonajlı kamyonlar kullanıldığında maliyet %34,90 azalmıştır. Sonuç olarak, tomruk kamyonu boyutları ile orman ürünlerinin transport maliyeti arasında yakın bir ilişki olduğu ortaya konulmuştur.

Anahtar Kelimeler: Orman transportu, optimum nakliyat rotası, CBS, Network Analyst

1. INTRODUCTION

The costs of forest harvesting, extraction of timber from forest site, and transporting them to forest depots are the important part of the expenses in forest management. Particularly, transportation of forest products constitutes a large part of the total timber production costs (Acar, 1998). The forest products extracted from the harvesting unit are first transported to temporary storage sites, called landing areas, and from there to the forest depots by mostly using logging trucks (Acar and Eroğlu, 2001). The most important factors affecting the cost of transportation are hourly unit cost and load capacity of trucks, road type and road condition.

In Turkey, logging companies who are willing to use large size logging trucks with high load capacity during transportation have difficulties in reaching the harvesting unit when the forest road standards are low, so they are often unable to participate in sales (Bayoğlu, 1997). After the forest products are loaded on the trucks according to the dimension and weight requirements of the General Directorate of Highways (GDH), they are allowed to use the highways. In order to transport the products exceeding these dimension and weight limits, a special transport permit should be obtained from the GDH.

The one way to increase the productivity of the transportation by logging trucks is to perform the truck transportation in a short time. Decreasing the transportation time depends on the standards of the road network that directly affect the travel speed of the logging trucks. If the road standards are improved, it will be also possible to increase the truck load that can be transported at one time, which increases the daily productivity. However, special care should be taken to remain within the load limits set by GDH when the load capacity is increased using additional axles.

It is important to determine the optimum transportation route that helps to minimize the transport time and eventually the transportation cost. Traditional methods of transportation planning, which are mainly based on the experience of the planner, are inadequate in developing the most suitable plans. For this reason, computer aided models have been developed in order to determine the transportation route with the lowest cost (Akay and Kılıç, 2015). In particular, algorithms known as network analysis models are effectively used to solve problems such as determining the shortest route and finding the least costly route (Başkent, 2004).

In recent years, the network analysis method integrated with GIS techniques has been used in the solution of transportation problems. In the solution process, factors that directly affect the transportation costs, such as truck size, can also be evaluated. Akay and Şakar (2010) used GIS techniques to determine the route that minimizes the transportation cost of forest products. In the study, two forest depots within the borders of Andirin FEC in the city of Kahramanmaraş were taken into consideration. The optimum route, which minimizes the unit transportation cost in the study, was determined by using the network analysis method.

In this study, Network Analyst module of ArcGIS 10.4 program was used to develop a decision support system that can assist planners to determine optimum transportation routes with minimum transportation costs. In the implementation of the system, three truck types with various load capacities, four forest harvesting units, three forest products, and a forest depot in İculaliye FEC was taken into consideration.

2. MATERIALS AND METHODS

2.1. Study Area

Within the scope of the study, optimum routes that minimize the transportation cost for three truck types were determined during the transportation of three forest products produced in four harvesting units (51, 74, 93, 95) to the existing forest depot in İclaliye FEC. The forest assets information of İnegöl FED, which is under the Forestry Regional Directorate of Bursa, is given in Table 1. The İnegöl FED has an area of approximately 179,000 hectares and 38% of the area is covered with forests. The FEC is located between 40˚22′57”-39˚51′44” north latitudes and 29˚15′48”-29˚51′21” east longitudes (Figure 1). Forests within the boundaries of the FEC shows the transition character between the Black Sea and the Mediterranean climate. The summer months are more like the Mediterranean Climate having hot weather with low precipitation rate while winter months are cold with high precipitation rate. The average annual rainfall is 517 mm. The average summer and winter temperature is 21.9℃ and 2.3℃, respectively. The annual average temperature is 12.4℃ (URL 1).

Table 1. The forest assesses of İnegöl FEC (ha) (URL 1)

FEC	Productive	Degraded Forest	Total Forest	Non-forested	Total Area
Boğazova	4,173.50	286.00	4,459.50	2,393.50	6,853.00
Hayriye	3,426.50	586.00	4,012.50	3,870.50	7,883.00
İclaliye	3,842.00	880.00	4,722.00	7,152.50	11,874.50
İnayet	3,147.60	383.80	3,531.40	3,154.00	6,685.40
İnegöl	8,912.00	2,325.00	11,237.00	18,874.00	30,111.00
Mezit	2,899.00	177.00	3,076.00	774.00	3,850.00
Oylat	4,386.00	566.00	4,952.00	1,447.50	6,399.50
Tahtaköpr	3,636.50	204.50	3,841.00	1,076.50	4,917.50
Yenice	6,402.00	2,123.20	8,525.20	17,451.50	25,976.70
Yenişehir	7,053.00	12,320.00	19,373.00	54,704.50	74,077.50

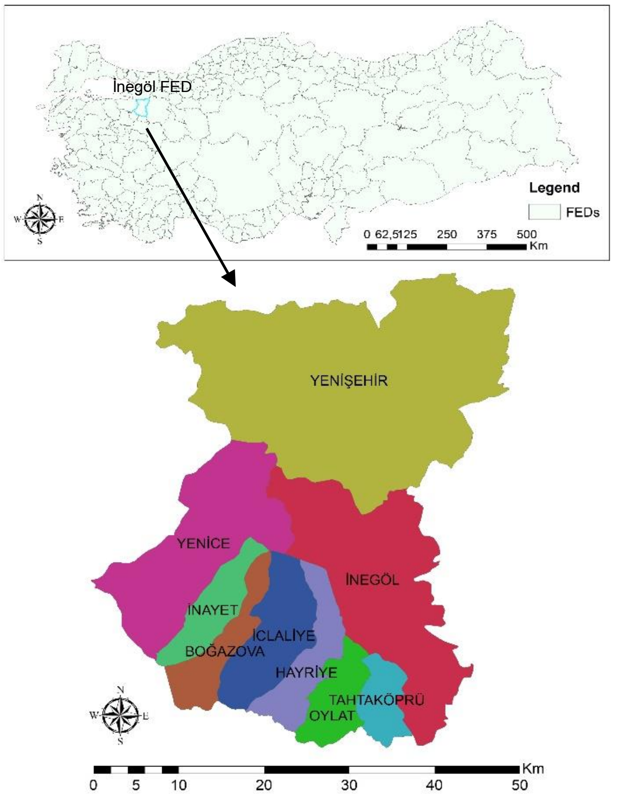

Figure 1. FECs in İnegöl Forest Enterprise Directorate (URL 1)

2.2. GIS Database

Three forest product types including 2nd quality Beech logs, 3rd quality Beech logs, and paperwood extracted from four harvesting units were evaluated within the scope of the study. The amount of forest products extracted from the landing areas and transported to the İclaliye Forest Depot were obtained from the İnegöl FED. In the study area, the landing areas and forest depot were visited in the field and their UTM coordinates were recorded with a handheld GPS. Then, a data layer was produced showing the location of the landing areas and forest depot in the study area.

Forest road network layer was generated using topographic maps of the study area obtained from the İnegöl FED. Unit transportation cost (TRY/m^3) of the logging trucks for each road section was calculated in the attribute table of the road network layer based on transportation time, hourly unit cost of logging trucks and their load capacities. In the attributes table of the road layer, the new fields including road length (km), road type (asphalt, gravel and forest road), vehicle speed (km/h), transportation time (hours) and transportation cost (TRY/m^3) were been added. Three logging truck types were classified as small, medium and large trucks depending on their load capacity.

Transportation time was calculated based on the length of the road section and average truck speed. The average vehicle speed was estimated for the road types based on the data obtained from FEC. The average vehicle speed was 60 km/hr, 40 km/hr, and 20 km/hr for asphalt, gravel and forest roads, respectively. These speeds represent the average of the loaded truck speed and the empty truck speed for each road section. The hourly unit cost and load capacity of the trucks were also obtained from the records of İnegöl FED. Table 2 shows the hourly unit costs and load capacities of logging trucks.

Table 2. Load capacities and unit costs of logging truck types

Truck	Hourly unit cost	Load capacities (ton≈m^3)
Small	40.55	10
Medium	77.44	20
Large	79.20	30

2.3. Network Analysis

"Network Analyst", which is one of the plugins of ArcGIS 10.4, was used to determine the optimum route based on network analysis method. In network analysis, the system consists of links (arc) and nodes where the links intersect. The links in the road network represent road sections and each link value represents the transportation cost for the road section. In this study, it was aimed to find the optimum route with the lowest total link values (Akay and Şakar, 2010). Unit transportation cost for each road section was computed based on the hourly unit costs of the trucks, load capacities and truck travel time (Equation 1) (Akay and Erdaş, 2007). Then, the truck travel time was calculated in Equation 2 (Akay & Şakar, 2010).

$$TC = \frac{C_{hr}}{\left(\frac{v}{t}\right)} \qquad (1)$$

TC : Unit transportation cost (TRY/m^3)
C_{hr} : Hourly unit costs of the trucks (TRY/hr)
v : Load capacities (m^3)
t : Truck travel time (hours)

$$t = \frac{2L}{S}(1+d) \qquad (2)$$

L : Road section length (km)
S : The average truck speed (km/hr)
d : Delay time ratio (%)

Delay time ratios for asphalt road, gravel road and forest road were considered as 5%, 10% and 15%, respectively (Akay and Erdaş, 2007). Unit transportation cost and truck travel time for each section was calculated using the "Field Calculator" in the options menu in the attribute table of the road network layer. Finally, the data layer showing the location of the landing areas and forest depot were overlapped with the road network layer.

After GIS database for network analysis was generated, the "Network Analyst" plugin was used in ArcGIS 10.4 platform to determine the optimum route that provides the most economical transportation from the landing areas to the forest depot. Firstly, a network database (Personal Geodatabase) has been defined using the "ArcCatalog" module. A new network dataset (Network Dataset) was developed by uploading the road network layer containing the values of the links (unit transportation cost) to be included in the network system. Then, the node (ND_Junctions) and link files (ND_Edges) were generated using the network dataset. Finally, network analysis application was performed using the “New Closest Facility” under the "Network Analyst" plugin in the "ArcMap" module (Figure 2).

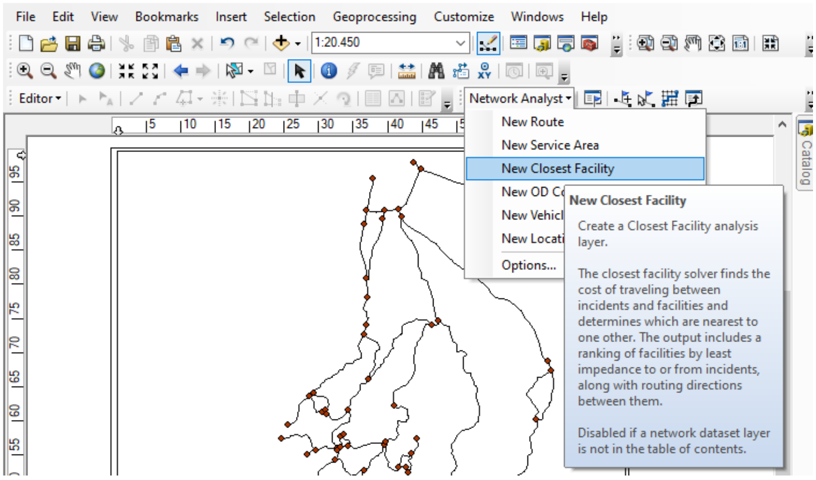

Figure 2. “New Closest Facility” under "Network Analyst" plugin of ArcGIS 10.4

3. RESULTS AND DISCUSSION

The volume of the forest products transported from the landing areas to the forest depot are given in Table 3. The locations of the landing areas and existing forest depot are shown in Figure 3. When the amount of forest products are compared, the forest product with the highest total volume was 3rd quality Beech logs (1955.17 m3), followed by paper wood (956.39 m3) and 2nd quality Beech logs (359.28 m3).

Table 3. The amount of the forest products (m^3)

Harvesting Units	2nd quality Beech logs	3rd quality Beech logs	Paper wood
57	33.99	407.92	190.45
74	18.03	560.44	341.98
93	252.27	608.22	265.48
95	55.03	378.59	158.51

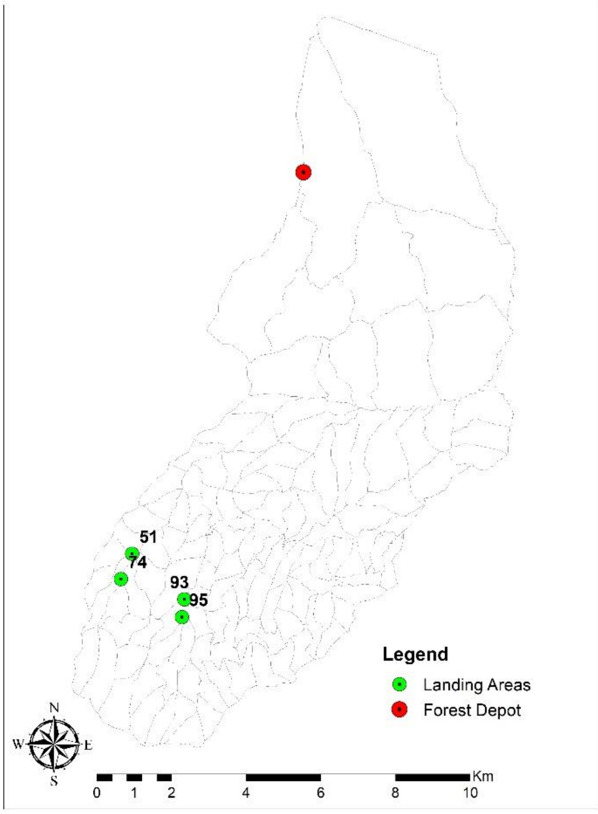

Figure 3. The landing areas and forest depot in the study area

The road network map produced on the basis of topographic maps is shown in Figure 4. Total road network length in the study area was calculated as 158.54 km. The most of the roads in the study area were forest roads (66.54%), followed by asphalt paved roads (18.28%) and gravel roads (15.18%). The total number of road sections produced in the road network layer was determined as 105. Using the proximity analysis method in the network analysis application, optimum routes with the lowest transportation cost were determined for the three truck types that deliver forest products from the landing areas to the forest depot.

The results indicated that the optimum routes for each truck type followed the same route to reach the landing areas in the harvesting units of 51 and 74. Likewise, the optimum routes reach the landing areas in the harvesting units of 93 and 95 followed the same route (Figure 5). Table 4 indicates the unit transportation costs of forest products transported from each landing area to the forest depot by three truck types. The results showed that the unit transportation cost decreased as the load capacity of the logging trucks increase (Akay and Şakar, 2010). The highest unit transportation cost was found in the landing area located in the harvesting unit of 95 due to the fact that it was located at a much more distant point than the landing areas of other harvesting units.

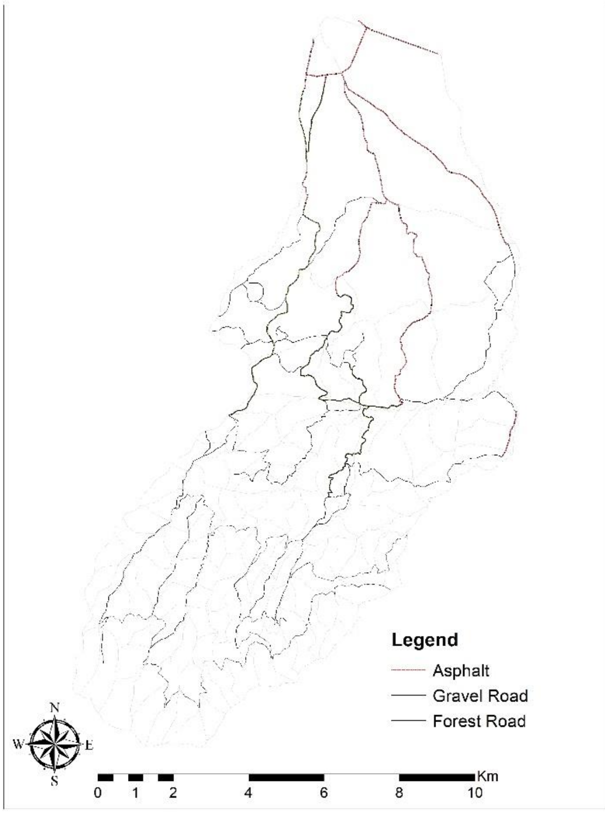

Figure 4. Road network layer

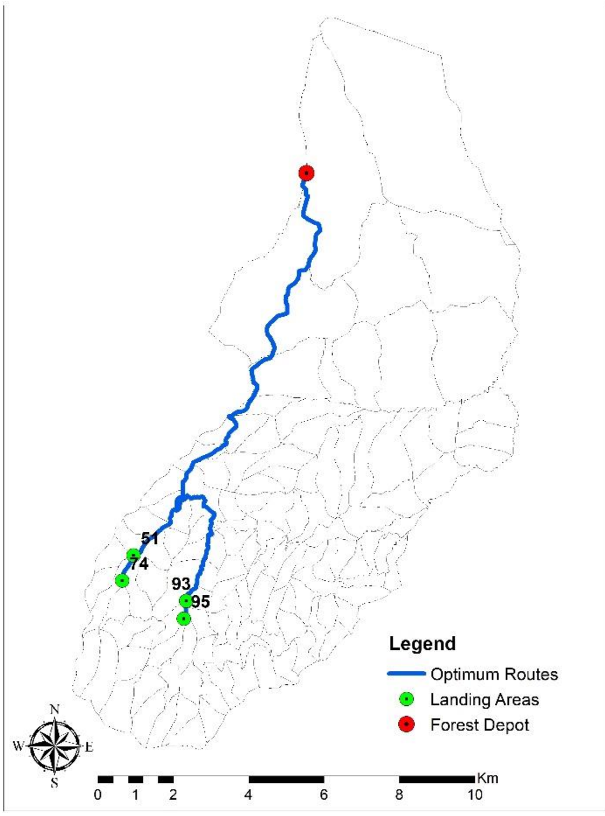

Figure 5. Optimum routes

Table 4. The unit transportation costs of forest products (TRY/m^3)

Harvesting	Small Size	Medium Size	Large Size
57	4,22	3,77	2,75
74	4,58	4,09	2,98
93	5,46	4,87	3,55
95	5,69	5,08	3,70

In the next step, taking into account the volume of forest products in the landing areas, total transportation costs for three truck types were calculated. Unit transportation costs for small, medium and large truck types and total transportation costs calculated based on product volumes are given in Tables 5, 6 and 7. The results showed that when using small, medium and large logging trucks, the total transportation cost was 16391 TRY, 14640 TRY and 10671 TRY, respectively. When using medium trucks instead of small trucks, the transportation cost of forest products decreased by 10.68% while the cost decreased by 34.90% when using large trucks. The forestry product with the highest transportation cost for all truck types was 3rd quality Beech logs followed by paper wood and 2nd quality Beech logs respectively. It has been observed that one of the most important factors on transportation cost was the product volume (Akay and Şakar, 2010).

Table 5. Total transportation costs for small size logging truck (TRY)

Harvesting Unit	2nd quality Beech logs	3rd quality Beech logs	Paper wood	Total Costs
57	143.53	1722.20	804.03	2669.76
74	82.47	2564.28	1564.72	4211.47
93	1376.35	3318.40	1448.42	6143.17
95	312.84	2152.17	901.11	3366.12

Table 6. Total transportation costs for medium size logging truck (TRY)

Harvesting Unit	2nd quality Beech logs	3rd quality Beech logs	Paper wood	Total Costs
57	128.20	1538.30	718.18	2384.67
74	73.67	2290.46	1397.64	3761.77
93	1229.38	2964.06	1293.76	5487.19
95	279.44	1922.36	804.89	3006.68

Table 7. Total transportation costs for large size logging truck (TRY)

Harvesting Unit	2nd quality Beech logs	3rd quality Beech logs	Paper wood	Total Costs
57	93.44	1121.23	523.46	1738.14
74	53.69	1669.47	1018.71	2741.88
93	896.07	2160.44	942.99	3999.50
95	203.67	1401.17	586.66	2191.51

4. CONCLUSIONS AND RECOMMENDATIONS

In this study, GIS-based network analysis, one of the modern methods, was used to determine the optimum route that minimizes the cost of transportation of forest products for different truck types. At the solution stage, routes with minimum transportation cost were determined to provide transportation of different forest products from the four harvesting units to the existing forest depot. It was determined that the total transportation cost of the products that reach the forest depot in the İclaliye FEC decreased due to the increase in truck load capacity. It has been observed that the distance of the forest depot to harvesting sites or landing areas affects the transportation cost closely. In addition, it was found that the volume of product carried was effective on the transportation cost. The method has the potentials to be developed prospectively. In order to improve the method presented in this study, it would be appropriate to take into account the harvesting, extraction and loading stages in cost analysis.

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