*Eur J Forest Eng 2017, 3(2): 52-60*

# Analyzing Compatibility of Geometrical Parameters of Logging Vehicles and Forest Roads

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## Abstract

Forest road is a complex and cost stage of the transportation. Forest roads enables to transportation of forest products. Well planned forest road networks improve effectiveness of transport. In order to provide safe and continuous transport long timber, long vehicles such as long truck, 18 wheels needed and appropriate curve widening. In the study, CAD based horizontal driving analysis were performed on existing forest road to determine curve widening requirements for truck and semitrailer. According to results, in case of using semitrailer with 4-meter platform width curve widening area will be needed 6 times more than using truck while, platform with 5-meter curve widening area will be needed 16 times more than truck usage. Consequently, driving analysis results is a beneficial approach for decision makers to achieve optimal solution and to minimizing transport operation costs in forestry.

**Keywords:** Driving analysis, timber transport, logging, forest operations

## 1. Introduction

Forest road is an essential structure for the forestry operations, also, a forest road network directly affects the effectiveness of timber transport and the other forest operations. Well planned forest road network is essential for the sustainable management of forest resources (Demir, 2007; Gumus et al., 2008). But, planning and developing of forest road networks are difficult and time-consuming activities (Rogers, 2005). However, in order for production stage to be effective, safe, comfortable and economical, appropriate planning of forest roads is of great importance (Abeli et al., 2000; Aruga et al., 2005). In a road planning stage, widening of curves is one of the most important stages of curve design (Chai, 2013). Inadequate curve geometrical parameter will decrease maneuverability capability of vehicles (Akgul et al., 2016). Also, in forest operations, largest vehicles are usually trucks and semitrailers (Senturk et al., 2007) which are limited maneuverability. In forest industry, demands were increased to produce long timber in past decades (Akgul, 2007). Transportation of the longer logs requires the utilization of longer transportation vehicles (Akgul, 2007; Demir et al., 2015). The roads with lower geometrical standards (horizontal curve radius, road platform width etc.) affect adversely maneuverability of the transportation vehicles. For that reason, road geometrical conditions directly effect transportation costs (Högnäs, 2001). In order to provide safe and continuous transportation for long timber, long vehicles such as long trucks with 18 wheels are needed along with appropriate curve widening (Akgul et al., 2016). Thus, selecting the best vehicle for timber transportation is important for both road cost and effective transport planning (Saikhani and Najnonian, 1994). With the advancement of technology, computer-based models were developed for road design and planning stages (Akgul et al., 2012) Several studies were performed with computer based forest road design and forest network planning (Akay and Sessions, 2005; Aruga et al., 2005; Gumus et al., 2008; Akay, 2009; Abdi et al., 2009; Najafi and Samani, 2010). Their results confirmed that using Computer Aided Software (CAD) and Geographic Information Systems (GIS) software can be helpful in planning and designing of forest roads. GIS based timber transport analysis has been also studied to minimize transportation costs. Many of these works employed the shortest path algorithm (Kumari and Geethanjali, 2010; Abraham et al, 2010; Chen et al, 2013). According to these works, transportation costs decrease by using the shortest path.

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Received 3 December 2017; Accepted 18 December 2017

Besides, using larger vehicles to transport more products at a time will reduce the cost of the transport.

In order for production procedures to be effectively, safely, comfortably and economically conducted; appropriate planning of forest roads is of great importance (Abeli et al., 2000; Aruga et al., 2005). In this study, dynamic driving analysis was used to determine curve widening requirements of a forest roads depending on its geometrical conditions and types of vehicles on it.

## 2. Materials and Methods

### 2.1. Study Area

The research area is located in southern plot of Istanbul University Education Research and Practice Forest close to Sariyer (Figure 1). The research area is at Thracian side of Marmara Region, between 28° 59' 17"– 29° 32' 25" east longitudes and 41° 09' 15" – 41° 11' 01" north latitudes. The research area is approximately 345 hectares.

Covered by vegetation, there are 7 forest roads with a total length of 17.96 km (Table 1). Types of forest roads in Turkey are divided into three types; primary forest roads, secondary forest roads and tractor roads. The most common roads constructed in Turkey are Type B secondary forest roads. According to forest network plan of the study area, it was suggested to reconstruct Type B forest roads because of the inadequate platform width and geometric inabilities.

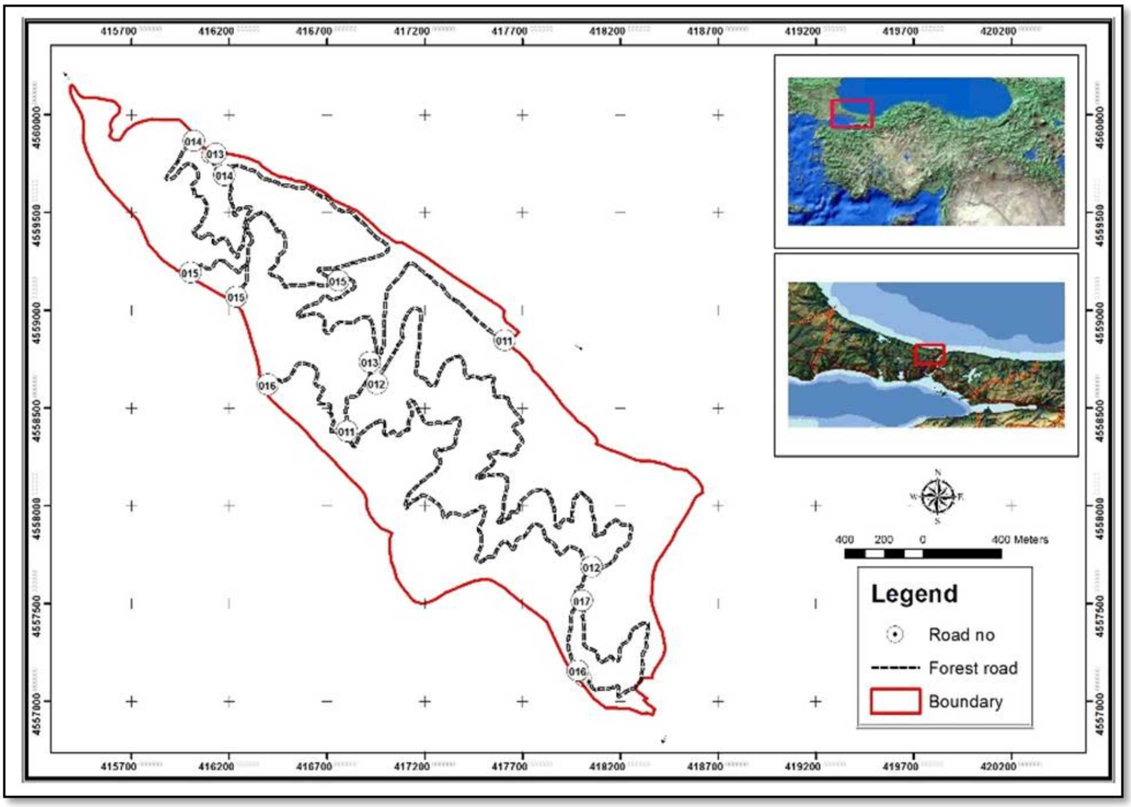


Figure 1. Location of study area

Table 1. Forest roads in research area

| Road No | Maintenance Activity | Total length (m) |
|---|---|---|
| 011 | Reconstruction | 1561 |
| 012 | Reconstruction | 4185 |
| 013 | Reconstruction | 2680 |
| 014 | Reconstruction | 1735 |
| 015 | Reconstruction | 1781 |
| 016 | Reconstruction | 4622 |
| 017 | Reconstruction | 1399 |
| | **Total** | **17963** |

### 2.2. Computer Aided Driving Analysis

Within scope of the study, driving analysis was performed in two phases. In the first phase, data were collected for driving analysis from existing forest road which are all Type B secondary forest road. Data accuracy is one of the most important factor for drive analysis. For that reason, in this study RTK (Real Time Kinematic) GPS (Global Positioning System) was used for data collection in the field. Nowadays, RTK GPS provides reliable results under forest environment (Gulci, 2015). Also, RTK technologies can supply centimeter positioning accuracy depending on terrain and satellite conditions (Bakula et al., 2009). Besides, RTK GPS are more cost-effective than other measuring platforms for small areas (Akgul et al., 2016). For those reasons, the geometrical coordinates of the existing forest roads platforms were measured with Pentax SMT-888 RTK GNSS (Global Navigation Satellite System). In this context, point coordinates were acquired with differential mode for reach high accuracy. Also CORS (Continuously Operating Reference Stations) Turkey network was used. Every coordinate point was measured as 10 seconds interval. XYZ coordinates of the road platforms were measured in every 10 meters along the alignment sections and 3 meters in horizontal curve sections.

In the second phase of the study, road data which were obtained by RTK GPS were evaluated in driving analysis software. In the study, Plateia software was used for horizontal driving analysis. Plateia software is an all-encompassing software solution both for designing new roads and reconstructing existing roads of all categories. Dynamic and manual driving analysis module of software provide instant solution for planning and design of forest roads for different vehicle types (Akgul et al., 2016). Also, driving analysis is a useful decision making tool for planner in the planning and construction stage of forest road (Demir et al., 2015). Plateia Software has a large scale of vehicle library for different purposes (i.e. bus, automobile, trailer etc.). The technical specifications of the vehicles in the library can be revised and modified for various purposes. In this study, truck and semitrailer vehicle types were used for horizontal driving analysis for the reason of their usage in the study area for logging operations on every road (Figure 2) (Table 2).

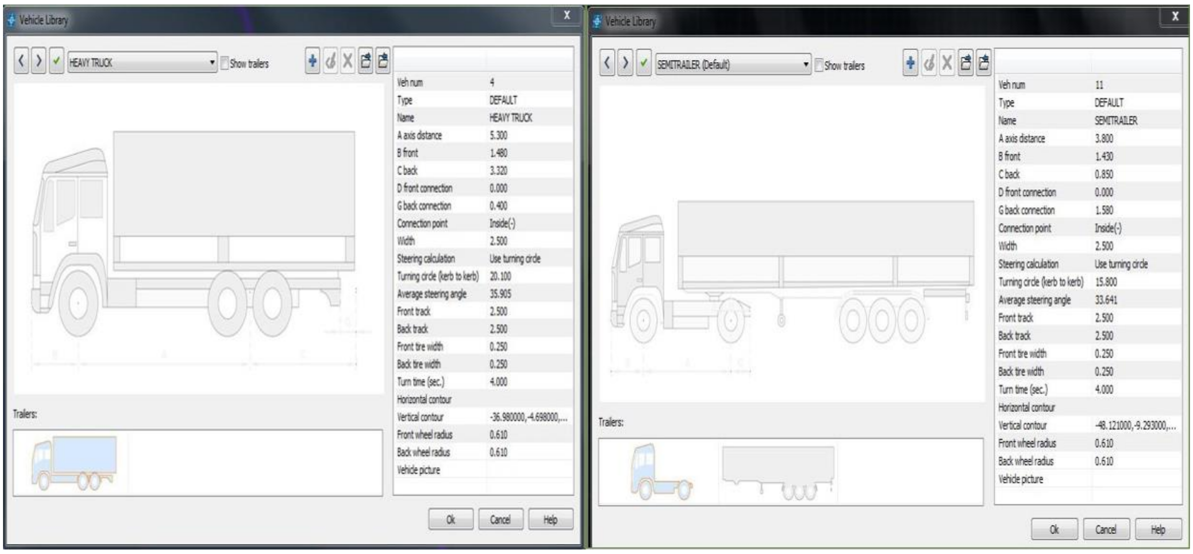

Figure 2. Vehicle library and geometrical dimensions of a truck and a semitrailer

Table 2. Technical specifications for vehicle utilization types defined in vehicle library on Plateia 2013 software

| **Technical Specifications of Vehicle** | **Truck** | **Semitrailer** |
|---|---|---|
| A axis Distance (m) | 5,30 | 3,80 |
| Width (m) | 2,50 | 2,50 |
| Front track (m) | 2,50 | 2,50 |
| Back track (m) | 2,50 | 2,50 |
| B front (m) | 1,48 | 1,43 |
| C back (m) | 3,32 | 0,85 |
| Turn time (sc) | 4,00 | 4,00 |
| Front wheel Radius (m) | 0,61 | 0,61 |
| Back well Radius (m) | 0,61 | 0,61 |
| Front tire width (m) | 0,25 | 0,25 |
| Back tire width (m) | 0,25 | 0,25 |

Horizontal driving analysis were made considering the middle axis of the forest road (Figure 3). For determining the optimum platform width in driving analysis stage the platform width of all roads were defined as both 5 and 4 meters because of the need of reconstruction for all existing roads. Finally, minimum and maximum platform widening amounts as square meter and minimum and maximum widening distances as meter were calculated for every road according to both vehicles of truck and semitrailer (Table 3). This entire processing and analysis works were conducted on workstation computer which has 2.6 GHz processor and 64 GB Ram running with Windows 8 Enterprise and 64-bit operating system.

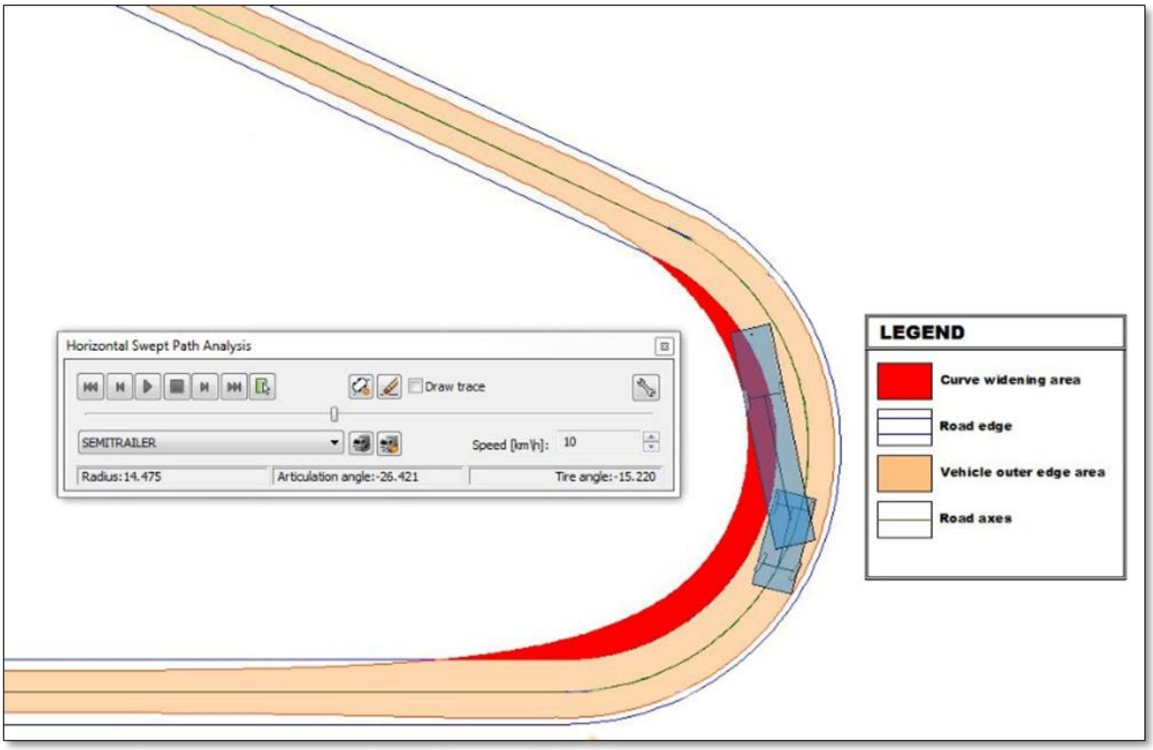


Figure 3. Simultaneous horizontal driving analysis for semitrailer (Akgul et al, 2017)

Table 3. Horizontal curve parameters of the forest roads in research area

| Road No | Geometric Properties Of Horizontal Curves | | |
|---|---|---|---|
| | Minimum radius (m) | Maximum radius (m) | Total Curve |
| 011 | 14.00 | 61.00 | 13 |
| 012 | 5.50 | 80.00 | 55 |
| 013 | 4.50 | 80.00 | 25 |
| 014 | 4.50 | 50.00 | 20 |
| 015 | 6.50 | 65.50 | 20 |
| 016 | 4.50 | 80.00 | 66 |
| 017 | 5.50 | 45.00 | 18 |

## 3. Results and Discussion

Horizontal driving analyses were performed for truck and semitrailer with 4-meter and 5-meter platform widths considering GPS coordinates which measured from middle axis of the existing forest roads. As it seen in Figure 4, driving analyses results were real-time driving analysis stage, it also can be seen in the same figure that the process of road platform widening is only needed in horizontal curves. There is no extra widening on alignments because of vehicle width is smaller than the platform width of the road.

### 3.1. Driving Analysis for 4-Meter Platform Width

Results of horizontal driving analysis which made for heavy truck with 4-meter platform width are listed on Table 4. According to the results, the minimum widening area was 2.296 $m^2$ on the left platform and 0.405 $m^2$ on the right platform. On the other hand, the maximum platform widening area was 47.590 $m^2$ on the left platform and 153.940 $m^2$ on the right platform. The total widening area was calculated as 145.569 $m^2$ for the left platform and 407.347 $m^2$ for the right platform.

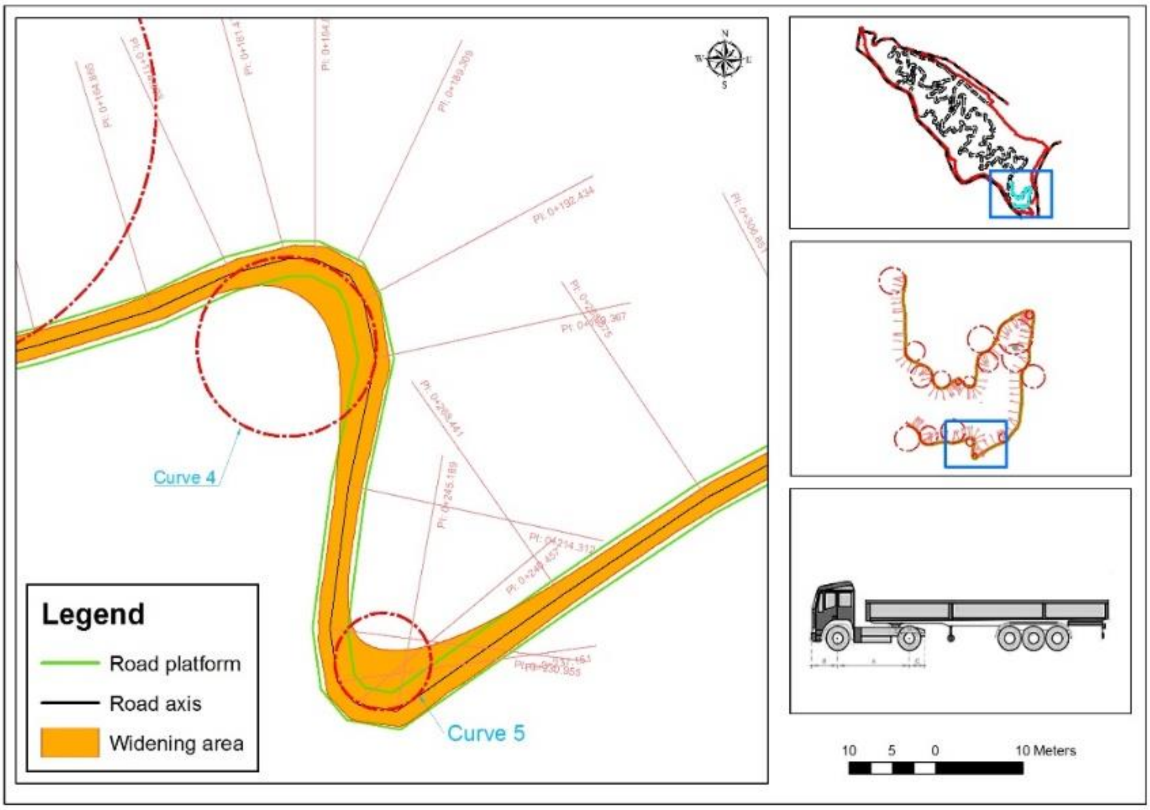


Figure 4. Real-time horizontal driving analysis for semitrailer on Road no 017

Table 5. Widening amounts and distances on horizontal curves with 4-meter platform width for

| Road No | Curve Widening (m²) | | | Maximum Widening Distance (m) | |
|---|---|---|---|---|---|
| | Left Platform | Right Platform | Total Width | Left Platform | Right Platform |
| 011 | 71.440 | 22.800 | 94.240 | 6.880 | 3.630 |
| 012 | 158.924 | 145.822 | 304.746 | 13.980 | 20.460 |
| 013 | 138.883 | 216.916 | 355.799 | 11.967 | 15.169 |
| 014 | 172.524 | 349.385 | 521.909 | 11.780 | 33.680 |
| 015 | 90.239 | 183.277 | 273.516 | 9.030 | 14.640 |
| 016 | 591.740 | 696.439 | 1288.179 | 41.273 | 54.555 |
| 017 | 157.805 | 153.810 | 311.615 | 15.400 | 10.308 |
| **TOTAL** | **1381.555** | **1768.449** | **3150.004** | **110.310** | **152.442** |

In total, the minimum curve widening on horizontal curve calculated on Road no 011 was 6.085 m$^2$, while the maximum curve widening area was calculated on Road no 016 as 201.53 m$^2$. On the other hand, maximum curve widening distance on left platform occurred at Road no 016 with 9.62 meter while maximum curve widening distance on right platform occurred at Road no 012 with 17.598 meter.

Within the context of the study, horizontal drive analysis results which made for semitrailer with 4-meter platform width are listed on Table 5. According to results, it was found that minimum platform widening area was calculated as 71.440 m$^2$ on the left platform and 22.800 m$^2$ on the right platform while maximum platform widening area was 591.740 m$^2$ on the left platform and 696.439 m$^2$ on the right platform. Also, total platform widening area of whole road was calculated as 1381.555 m$^2$ for the left platform and 1768.449 m$^2$ for the right platform. In total, minimum curve widening on horizontal curve was calculated on Road no 011 as 94.240 m$^2$, while maximum curve widening area was calculated on Road no 016 as 1288.1794 m$^2$. In addition to these, maximum curve widening distance on left platform occurred at Road no 016 with 41.273 meter while maximum curve widening distance on right platform occurred at Road no 012 with 54.555 meter.

### 3.1. Driving Analysis for 5-Meter Platform Width

According to horizontal driving analysis result which made for semitrailer with 5-meter platform width, it was calculated that maximum platform widening area was 7.674 $m^2$ on the left platform and 31.425 $m^2$ on the right platform (Table.6). Also, roads' total platform widening area was calculated as 18.236 $m^2$ for the left platform and 106.453 $m^2$ for the right platform. In total, minimum curve widening on horizontal curve was calculated on Road no 011 as 0.287 $m^2$, while maximum curve widening area was calculated on Road no 012 as 32.668 $m^2$. On the other hand, maximum curve widening distance on left platform occurred at Road no 017 with 1.998 meter while maximum curve widening distance on right platform occurred at Road no 012 with 7.141 meter.

Horizontal drive analysis results for semitrailer with 5-meter platform width were listed on Table.7. It was calculated that minimum platform widening area was 71.440 $m^2$ on the left platform and 22.800 $m^2$ on the right platform, while maximum platform widening area was 591.740 $m^2$ on the left platform and 696.439 $m^2$ on the right platform. Also, total platform widening of whole road area was calculated as 1381.555$m^2$ for the left platform and 1768.449 $m^2$ for the right platform. In total, minimum curve widening on horizontal curve was calculated on Road no 011 as 32.007 $m^2$ while maximum curve widening area was calculated on Road no 016 as 665.665 $m^2$. On the other hand, maximum curve widening distance on left platform occurred at Road no 016 with 41.273 meter while maximum curve widening distance on right platform occurred at Road no 012 with 54.308 meter.

Table 6. Widening amounts and distances on horizontal curves with 5-meter platform width for heavy truck

| Road No | Curve Widening (m²) | | | Maximum Widening Distance (m) | |
|---|---|---|---|---|---|
| | Left Platform | Right Platform | Total Width | Left Platform | Right Platform |
| 011 | 0.287 | 0.000 | 0.287 | 0.000 | 0.000 |
| 012 | 1.243 | 31.425 | 32.668 | 0.518 | 7.141 |
| 013 | 0.970 | 11.794 | 12.764 | 0.515 | 2.777 |
| 014 | 5.577 | 24.755 | 30.332 | 1.118 | 6.208 |
| 015 | 0.000 | 6.617 | 6.617 | 0.000 | 2.099 |
| 016 | 2.485 | 29.503 | 31.988 | 0.899 | 6.964 |
| 017 | 7.674 | 2.359 | 10.033 | 1.998 | 0.765 |
| **TOTAL** | **18.236** | **106.453** | **124.689** | **5.048** | **25.954** |

Table 7. Widening amounts and distances on horizontal curves with 5-meter platform width for semitrailer

| Road No | Amount of Widening (m²) | | | Maximum Widening Distance (m) | |
|---|---|---|---|---|---|
| | Left Platform | Right Platform | Total Width | Left Platform | Right Platform |
| 011 | 29.739 | 2.268 | 32.007 | 3.470 | 0.780 |
| 012 | 186.592 | 400.591 | 587.183 | 19.759 | 40.231 |
| 013 | 39.507 | 137.757 | 177.264 | 5.156 | 13.281 |
| 014 | 75.244 | 235.726 | 310.97 | 6.750 | 28.160 |
| 015 | 19.457 | 99.196 | 118.653 | 3.010 | 12.120 |
| 016 | 231.287 | 434.378 | 665.665 | 21.561 | 41.408 |
| 017 | 84.465 | 82.271 | 166.736 | 10.410 | 7.540 |
| **TOTAL** | **666.291** | **1392.187** | **2058.487** | **70.116** | **143.520** |

According to the platform width depending on vehicle types, the results of total widening amounts on horizontal curves for each road are indicated on Table 8, Figure 5 and Figure 6. Regarding to these results, it can be indicated as:

- Existing horizontal curve widths are not appropriate for timber transportation with truck and semitrailer because of the inadequate curve widening area,
- In case of using semitrailer for timber transport on the forest roads with 4-meter platform width, the curve widening area will be needed 6 times more than the cases while using truck,
- In case of using semitrailer for timber transport on forest road platform with 5-meter platform width, the curve widening amount will be needed 16 times more than the truck usage,
- In case of using truck for timber transport on forest road platform with 4-meter platform with, the curve widening area will increase approximately 4 times more than road platform with 5-meter width,
- In case of using semitrailer for timber transport on forest road platform with 4-meter width, the curve widening area will increase approximately 1.5 times more than road platform with 5-meters width.

Table 8. Total Widening amounts on horizontal curves for each road depending on vehicle type and platform width

| Road No | Curve Widening ($m^2$) Platform width=4 m Truck | Semitrailer | Platform width=5 m Truck | Semitrailer |
|---|---|---|---|---|
| 011 | 6.085 | 94.24 | 0.287 | 32.007 |
| 012 | 146.755 | 304.746 | 32.668 | 587.183 |
| 013 | 41.696 | 355.799 | 12.764 | 177.264 |
| 014 | 88.614 | 521.909 | 30.332 | 310.97 |
| 015 | 27.427 | 273.516 | 6.617 | 118.653 |
| 016 | 201.53 | 1288.179 | 31.988 | 665.665 |
| 017 | 40.809 | 311.615 | 10.033 | 166.736 |
| **Total** | **552.916** | **3150.004** | **124.689** | **2058.478** |

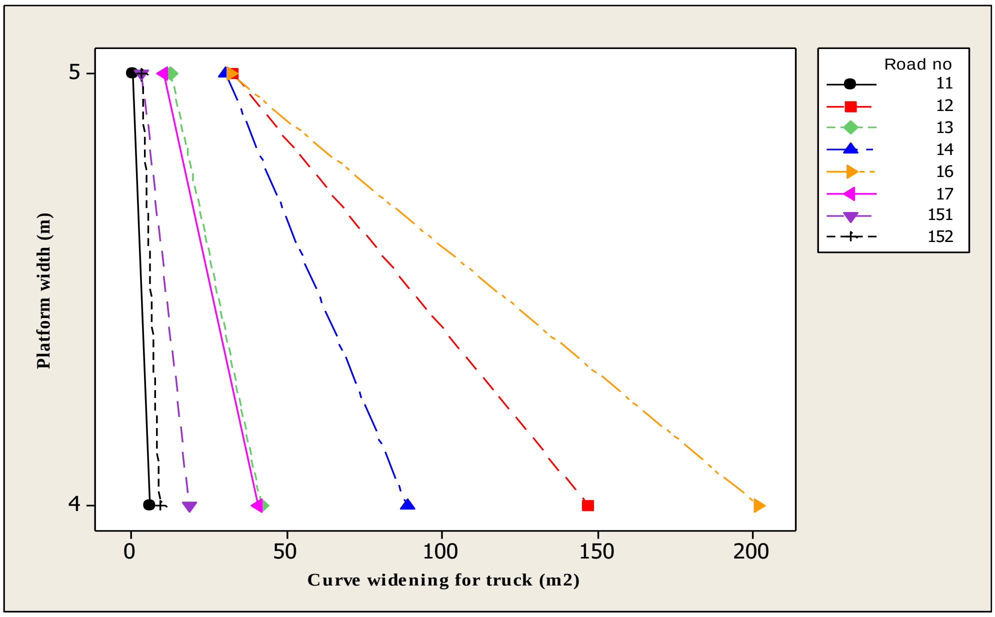


Figure 5. Scatter plot of platform width and curve widening for truck

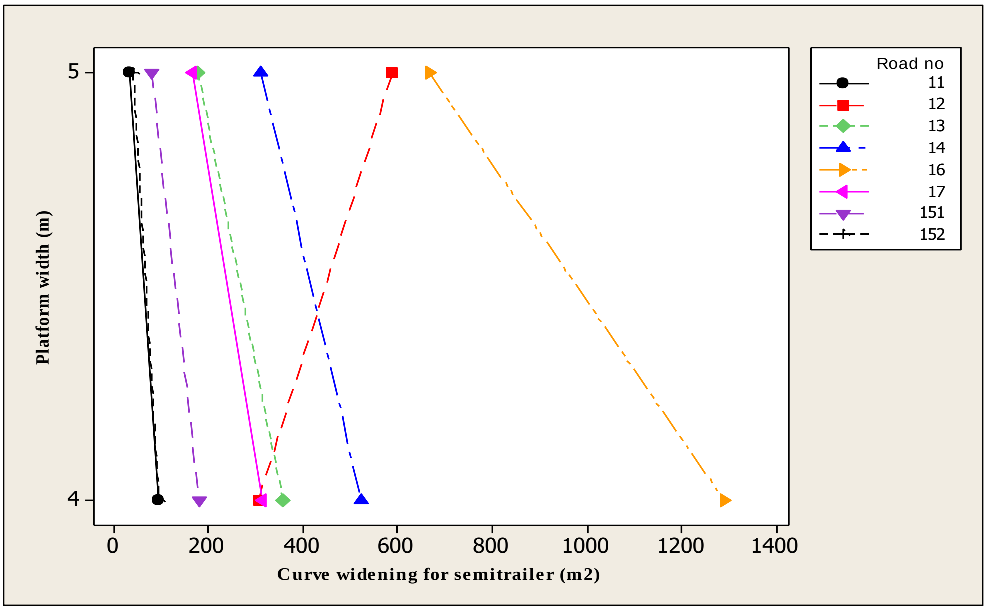


Figure 6. Scatter plot of platform width and curve widening for semitrailer

In case of using semitrailer for timber haulage in study area, totally 3150 $m^2$ widening area was required. In a similar study, Akgul et al. (2016) analyzed maneuverability capability of recreational vehicles on forest roads and they suggested that driving analysis is cost effective tool for road planning and design works. Parsakhoo and Hosseini (2009) indicated that appropriate vehicle selection is one of the most important factors of transport decisions and timber transportation corresponds to total operating cost. Cox (1998) emphasizes that, changes in geometrical dimensions of vehicles can effect road geometric standards. Parsakhoo and Hosseini (2009) stated that changes in road geometric standards due to vehicle types also effect road construction and maintenance costs. Akgul et al. (2017) stated that, prediction of curve widening will assist forest engineers for accurate estimation of earthworks.

## 4. Conclusions

Within the scope of study, widening requirements of horizontal curve were calculated according to two different logging vehicle types depending on different platform widths. According to results of driving analysis, existing horizontal curve widths are not appropriate for timber transportation with semitrailer because of the inadequate curve widening area. Consequently, increasing of a forest road width in the research area will be efficient and also useful for timber hauling while considering the maneuverability capability of various vehicles. On the hand, reconstruction of all roads in the area is a costly process.

Forest road reengineering is a costly and laborious process. With the development of the technology, vehicles with long and different maneuverability have been produced. Recently, demand of forest industry on long log production has been increasing, and therefore, road planners may encounter with complex decision making process in road reconstruction stage in the near future. As presented in this study, driving analysis ca be used effectively and easily for optimum vehicle selection purposes in timber transportation. In complicated decision making process such as transport planning, driving analysis will help decision makers to achieve optimal solutions in forestry activities.

## Acknowledgement

This work was funded by the Scientific and Technological Research Council of Turkey under Grant 113O975.

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