



INVESTIGATION OF RECREATIONAL VEHICLES MANEUVERABILITY ON FOREST ROADS BY COMPUTER-AIDED DRIVING ANALYSIS

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Abstract. Forest road planning is a time-consuming and complicated process both because it requires environment-friendly road building, and due to the requirement to observe economic costs. This costs will be increase depending on maneuverability requirements of vehicle dimension. The main aim of this study is to analyze maneuverability of recreational vehicles on forest roads that primarily serve utilization of vehicles intended for production as well as geometrical characteristics of roads on computer environment. Both dynamic horizontal driving analysis and dynamic vertical driving analysis can be made with Autopath driving analysis module of Plateia 2013 software. Computer-aided horizontal driving analysis, which is used in examination of opportunities for utilization of available roads by different vehicle types, appears as an effective method for the decision maker in consideration of geometrical standards of vehicles during decision-making process. Graphical report is another output of driving analysis which visually presents vehicle maneuverability. In this context, Maneuverability of automobile, midibus and bus were analyzed on forest road with 4 m platform width. As a results of this study, it was concluded that computer-aided driving analysis is a beneficial tool in decision making process for re-planning of forest roads. As a consequence, it is considered that driver safety, as well as project costs, would increase by utilization of driving analysis during forest road planning and design.

Keywords: driving analysis, forest roads, Plateia 2013 software, recreational vehicles, vehicle utilization type.

1. Introduction

The earliest developments in road technique started with the invention of wheel around 5000 B.C. Developments in road and transport vehicles used by mankind advanced in line with the developments in civil life standards. A road can be defined as a land strip open to public use for any vehicle and pedestrian transportation (Umar, Yayla 1994) or a leveled surface that serves pedestrian or vehicle passage or an engineering structure that transfers any load to the ground and that comprises of infra and superstructure (Hasdemir, Demir 2000). General structural principle in road construction is to ensure an economical road structure with sufficient safety and technical characteristics without causing any permanent deformation on both the road itself and the natural ground, on which the road is located, against static and dynamic effects arising from vehicles, other external effects, as well as internal effects caused by physical and chemical characteristics of the material comprising the structure, depending on the function of the structure (Erdas 1997). Roads that comprise the infrastructure of shipment and transportation play

a vital role in performance of forestation activities; thus, transportation of forest products, produced within the forest, from the place of production to industry or consumption centers with the most convenient methods by the most affordable means, as well as ensuring sustainability of the forest during the process, require planning of road networks (Bayoglu 1997).

Forest roads can be defined as: “Structures that ensure transportation of wood-based and non-wood forest products from where it is produced to where it will be used”. These roads operationalize forests in addition to ensuring transportation of wood raw materials, personnel and equipment, as well as satisfying road requirements and recreational demands of forest villages. Therefore, forest roads provide economic, social and even cultural benefits. Forest roads are important structures that ensure transportation during the process from establishment stage until production stage of a forest. Road planning and production works are among important elements of forestry activities (Abdi *et al.* 2009). In order for production procedures to be effective, safe, comfortable and

economical, appropriate planning of forest roads is of great importance (Abeli *et al.* 2000; Aruga *et al.* 2005).

Forest road design is a complicated process that requires consideration of ecological and economic factors. During this process, the designer should determine the final route among an adequate number of alternative roads, which meets technical and ecological requirements and total cost of which is the lowest (Akay *et al.* 2004, 2014). Planning and developing forest road networks are difficult and time-consuming activities. By means of the utilization of geographical information systems (GIS), alternative routes are also taken into consideration and therefore both loss of time is avoided and more reliable designs are made (Rogers 2005).

Types of forest roads in Turkey are divided into three; primary forest roads, secondary forest roads and tractor roads. These roads show differences such as ditch and road width, amount of assets to be transported in a year, curve radius and slope percentages, etc. Technical characteristics of these roads have different values (Table 1) (OGM 2008). These geometrical characteristics represent the minimum standards that should be observed during planning, design and construction of forest roads. In our country, forest roads are mostly built according to the Type B Secondary Forest Road Standard, while average road width is 5 m together with the platform and the ditch (OGM 2008).

Currently, it has become necessary to improve the standards of forest roads in consideration of both the demand of forest product buyers to obtain products quicker and the obligation to minimize damages on products during loading and unloading in warehouses within forests. Expected characteristics of forest products changed in line with the demands of the industry. Logs that used to be produced in certain lengths became unable to satisfy the demands of consumers. Producers sell planted trees or cut demanded products at determined lengths when appropriate. Therefore, it might be required to transport longer logs or even complete trunks (Akgul 2007). This requires the utilization of longer transportation vehicles such as trailer trucks. However, the forest roads of adequate standards

for movement of such transportation vehicles are currently rare in Turkey. This obstructs provision of products in standards demanded by consumers, and therefore utilization of forest products is limited.

As forestry practices developed, fields of utilization and standards of forest roads changed pursuant to a functional and sustainable sense of management. Planning and design standards of forest roads have certain differences between production and recreational forests besides their common aspects. These differences arise from the characteristics of utilization functions of forests. When approaching the subject in this context, it is necessary to classify forest roads according to functional utilization principles in line with the expectations of the society and forestry practice requirements, and to determine road standards according to such classifications (Akgul 2007).

Forest roads serve various fields of utilization according to their utilization purposes (Potocnik 1996). These purposes classified as:

1. Utilization for forestry practices;
2. Providing transportation to villages;
3. Hunting;
4. Access to recreational facilities within forests (shelter, etc.);
5. Access to hunting facilities within forests (hunting lodges, hunting grounds, etc.);
6. Access to hunting and wild animal breeding places and stations;
7. Access to mountain huts;
8. Transportation within the forest;
9. Utilization for tourism purposes;
10. Utilization for protection purposes;
11. Utilization for military purposes;
12. Utilization for sports and recreational purposes.

Types of utilization of vehicles on roads can also differ according to geometrical characteristics of roads in addition to the functions they serve. Geometrical standards of forest roads in Turkey have inferior characteristics than road standards in developed countries. Forest roads are generally used by four different vehicle types.

Table 1. Geometrical standards for forest roads (OGM 2008)

Road type	Unit	Primary forest road	Secondary forest road				Tractor road
			Type A	Type B			
				SBT*	NBT*	EBT*	
Platform width	m	7	6	5	4	3	3.5
Number of lanes	Units	2	1	1	1	1	1
Maximum slope	%	8	10	9	12	12	20
Minimum curve radius	m	50	35	20	12	8	8
Lane width	m	3	3	3	3	3	3
Shoulder width	m	0.50	0.50	0.50	0.50	0.50	-
Ditch width	m	1.00	1.00	1.00	1.00	0.50	-
Pavement width	m	6	5	4	3	3	-
Bridge width	m	7+(2×0.6)	6+(2×0.6)	5+(2×0.6)		4+(2×0.6)	-

*SBT: Standard B type forest road,

NBT: Normal B type forest road, EBT: Extreme B type forest road

1. Vehicles intended for production;
2. Vehicles intended for management and protection;
3. Recreational vehicles;
4. Road building and maintenance vehicles.

From their initial establishment, forest roads had been planned primarily for production purposes and, in time, they served different functions. In Turkey, mere wood production was replaced by functional forestry as functional forestry activities began after the year 2000. Thus, forest roads started to serve different utilization purposes. Therefore, types of vehicles using forest roads have changed also.

With the advancement of technology, computer software intended for road planning and design were developed. Some of these software used in road planning can be listed as Advanced Road Design, Allplan, Anadelta Tessera, AutoCAD Civil 3D, AutoRoads, Bentley InRoads, Bentley MXROAD, CAD&PILLAR, Carlson Civil, Civil Designer, Digicorp Civil Design, Diolkos, HEADS Pro, HighRoad, HY-SZDL, ISTRAM ISPOL, KeyTERRA-FIRMA, LIS-CAD, NetCAD, Novapoint, NovaTDN, Odos, Optimum Road Design Model, PDS, Plateia, RoadEng, SierraSoft ProSt, VESTRA Road. Software other than RoadEng were planned and developed only for the purpose of road planning (Akgul *et al.* 2012). Such software are intended for the design and planning of new roads. Certain significant studies attempted to exhibit the utilization opportunities for above mentioned software in planning forest roads and forest road networks (Akay 2003; Altunel 2006).

Both dynamic horizontal driving analysis and dynamic vertical driving analysis can be made with Autopath driving analysis module of Plateia 2013 software, which has been analyzed within the scope of this study (Fig. 1). By the capability of this feature, maneuverability and safe driving conditions for the vehicle types were analyzed depending on the design speed of the road.

Primary purpose of the study is to analyze the means of utilization and maneuverability of recreational vehicles on forest roads that primarily serve utilization of vehicles intended for production as well as geometrical characteristics of roads on computer environment. Maneuverability of vehicles depending on geometrical characteristics of roads is also important factor for traffic and drive safety. For this purpose, utilization opportunities for recreational vehicles on an example forest road that serves vehicles intended for production, management and protection were analyzed depending on geometrical conditions of roads and types

of vehicles with driving analysis module of Plateia 2013 software.

2. Material and method

2.1. Material

2.1.1. Research area

The research field determined as the subject of the study is the northern plot of Istanbul University Education Research and Practice Forest. The research field 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 according to Greenwich. Average slope of the research field is 28.41%, maximum slope is 90%, while standard deviation is 16.27. Climate data, from 1980 to 2009 was obtained from Bahcekoy Meteorology Station (Table 2). The highest average temperature value for the field was measured as 22.1 °C in August. The highest temperature was measured as 40.7 °C, while the lowest temperature was measured as -11.4 °C in February. In terms of annual precipitation, the highest precipitation was recorded in December as 183.2 mm, while the lowest precipitation was recorded in July as 39.4 mm. Total annual precipitation is 1111.4 mm. The highest relative humidity was measured in January as 81.4%. The month with the highest average in terms of the number of snow-covered days is February with 5.6 days. Prevailing wind direction is Northeast according to *State Meteorology Affairs General Directorate* data of 2013.

2.1.2. Location and technical characteristics of the forest road in the study area

Within the scope of the study, forest road no. 005 of Istanbul University Education Research and Practice Forest was determined as the road where driving analysis was conducted. The road no. 005 is classified as Normal Type-B forest road pursuant to the communiqué No. 292 titled "Planning, Building and Maintenance of Forest

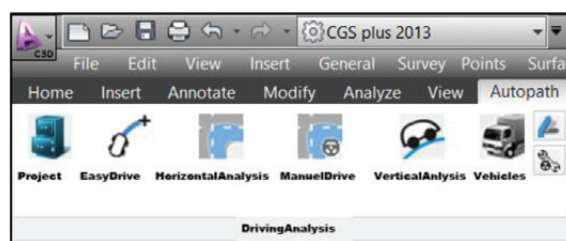


Fig. 1. CGS Plateia driving analysis module interface

Table 2. Certain climate data from Bahcekoy Meteorology Station (1980–2009) according to *State Meteorology Affairs General Directorate* data of 2013

Parameters	Months												Annual
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Mean temperature, °C	4.6	4.3	6.3	10.7	15.2	19.6	22.0	22.1	18.3	14.3	9.5	6.5	12.7
Max temperature, °C	18.3	22.2	25.4	32.9	33.9	37.3	40.7	37.9	34.1	33.1	25.2	19.9	40.7
Min temperature, °C	-11.0	-11.4	-8.2	-2.2	0.3	6.1	8.2	8.0	6.4	0.2	-2.8	-7.6	-11.4
Rainfall, mm	149.9	111.2	101.0	56.3	44.1	42.2	39.4	63.8	70.5	117.3	132.5	183.2	111.4

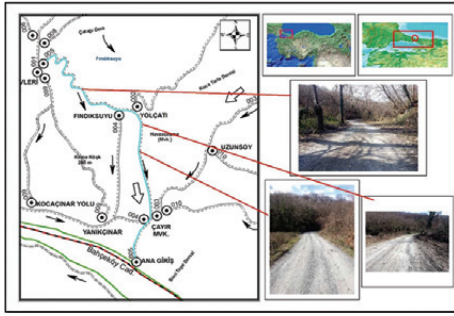


Fig. 2. Geographical location of the road No. 005

Table 3. Technical specifications for vehicle utilization types defined in vehicle library of Plateia 2013 software

Technical specifications of vehicle	Automobile	Midibus	Bus
A axis distance, m	2.70	3.38	5.80
Width, m	1.76	2.27	2.50
Front track, m	1.76	1.91	2.50
Back track, m	1.76	1.65	2.50
B front, m	0.94	1.69	2.85
C back, m	1.10	2.425	3.35
Turn time, sc	4.00	4.00	4.00
Front wheel radius, m	0.33	0.42	0.52
Back wheel radius, m	0.33	0.42	0.52
Front tire width, m	0.18	0.175	0.25
Back tire width, m	0.18	0.40	0.60

Roads”. Road platform width is 4 m and total length is 1335 m (Fig. 2). The forest road is the main arterial road in the research forest, in addition to being the shortest way to Bilezikci ranch, which is a historical structure. The road No. 005 has a recreational potential due to the access to Bilezikci ranch and old sycamore trees along the road.

2.2. Method

2.2.1. Road data input

During the first stage of the study, current status of the road should be primarily modeled on computer environment in an accurate manner in order to conduct driving analyses on Plateia 2013 software and to be able to obtain healthy results. Nowadays in forestry applications, RTK GPS (Gulci et al. 2015), Satallite data (Jacobsen 2013; White et al. 2010), Airborne Lidar system (Azizi et al. 2014; Guan et al. 2014) and UAV systems (Akgul et al. 2016; Uysal et al. 2015) are used to generate Digital Elevation Model (DTM) with high precision. However, conventionally RTK GPS are more economical and cheaper than other systems to generate DTM for small areas. For that reason, in this study, geometrical characteristics of the road platform of the forest road No. 005, which was identified within the limits of the research field, were measured with RTK GPS and transferred onto computer environment (Kahveci et al. 2011; Mekik, Arslanoglu 2009; Ors 2004; Pirti et al. 2009; Uyar 2005). In measurements of the road platform taken with RTK GPS in every 10 meters at alignment sections of the road and in every 3 meters in addition to curve start-curve middle-curve end points at curves within geometrical standards of the forest road No. 005:

- a) middle points of road platforms;
- b) right and left edges of roads (end points of right and left shoulders);
- c) locations corresponding to end points of cutting slopes and embankment slopes of roads;
- d) points where road platform width change;
- e) curve and stream crossing points;
- f) also, points deemed appropriate.

X (northern coordinate), Y (eastern coordinate) and Z (height) coordinate information were registered.

2.2.2. Computer-aided driving analysis

Plateia 2013 software was preferred as it provides the user with both dynamic and manual driving analysis, and it can provide instant solutions for re-planning of forest road route and different vehicle types in consideration of the difficulties in planning forest roads. Available vehicle library of Plateia 2013 Autopath module was revised according to recreational vehicles used in our country and a new library was created by introducing determined new vehicle types (automobile, midibus and bus) and their specifications into the software in order to determine the alternative road geometry that may appear in case geometrical characteristics and routes of available roads are improved (Table 3). For the vehicle types created under the names automobile, midibus and bus the data reflecting maneuverability such as axis distance, width, front and back tracks, B front and

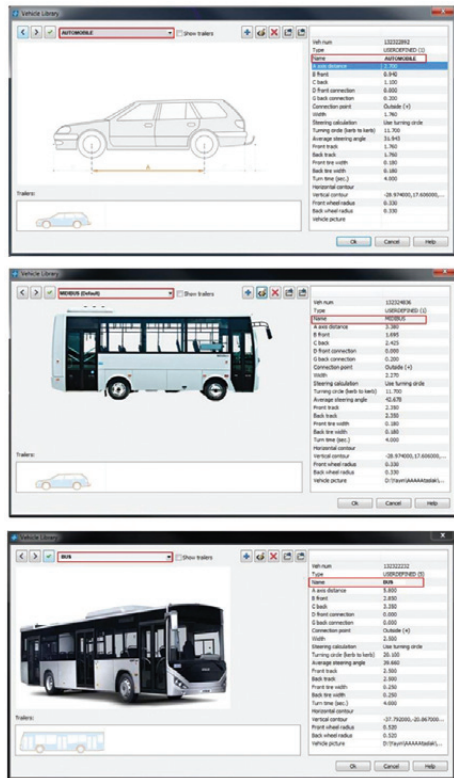


Fig. 3. Creation of a vehicle library for automobile, midibus and bus type vehicles in Plateia 2013 software

C back, turn time, front and back wheel radius, front and back tire width were entered for each vehicle type (Fig. 3).

Plateia 2013 software has a vehicle library intended for vehicles used mostly in highway transportation such as various types of automobiles, trucks and trailers. This vehicle library can be modified according to the desired vehicle type.

During the study, route of the road No. 005 obtained from road network plan of Istanbul University Education and Research Forest was defined as the middle axis of the road, while road platform width was defined as 4 m.

After vehicle library had been created, horizontal driving analyses were made in consideration of the road axis and road platform determined for each vehicle type. Horizontal driving analyses were simultaneously exercised during assessment stage (Fig. 4). Thus, simultaneous horizontal driving analyses provided the opportunity to simultaneous observation and assessment of, as well as intervention in the area where front and back axles and vehicle parts of the vehicle type used during planning stage uses the available road platform.

According to the driving analysis results, graphical analyses were made regarding wheel turns, and graphical driving reports were created pursuant to technical specifications of vehicles and available geometrical characteristics of the road as a result of the analysis conducted on the available road axis according to geometrical and technical specifications defined in Plateia vehicle library for every vehicle type.

3. Results

3.1. Horizontal driving analysis

It was seen during the assessment that, since, according to the results of horizontal driving analyses, the route was straight in the first 975 m of the road, there was not a geometrical restriction obstructing and/or limiting driving safety and maneuverability of vehicles in terms of available geometrical conditions of the road. Therefore, results obtained from the driving analysis were provided for the last 360 m of the forest road No. 005 comprising curves which might create obstacles for different vehicle types.

According to driving analysis results, total surface area of available road platform on the road No. 005, with the total 1335 m length and 4 m platform width, is 5342 m².

According to the results of horizontal driving analysis made for the automobile (Fig. 5), it was seen that the total road platform area required for safe driving according to available technical specifications of the automobile was 2494 m² and that the road did not require any expansion.

According to the results of horizontal driving analysis made for the midibus (Fig. 6), it was calculated that the total road platform area required for safe driving and maneuverability according to available technical specifications defined in vehicle library was 3323 m². Although such calculated road platform area is smaller than the available road platform area, maximum expansion distance for the midibus is 0.53 m for the right platform and 0.23 m for the left platform as seen in Table 4. Total platform

expansion requirements in curves are: 0.13 m² on the left platform and 0.86 m² on the right platform.

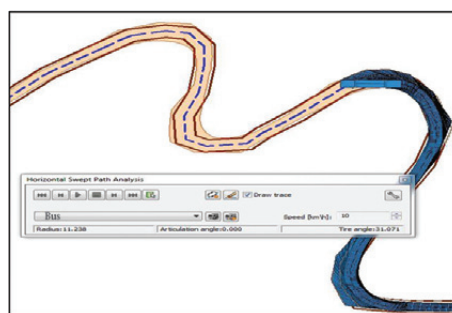


Fig. 4. Simultaneous horizontal driving analysis for bus

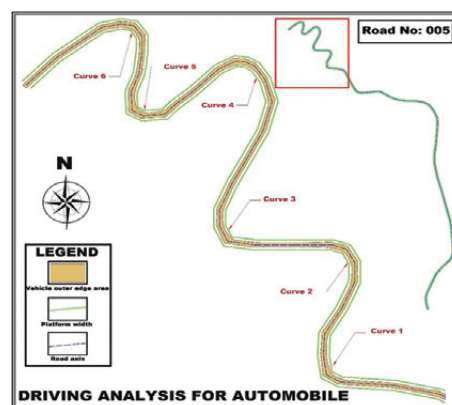


Fig. 5. Results of horizontal driving analysis for automobile

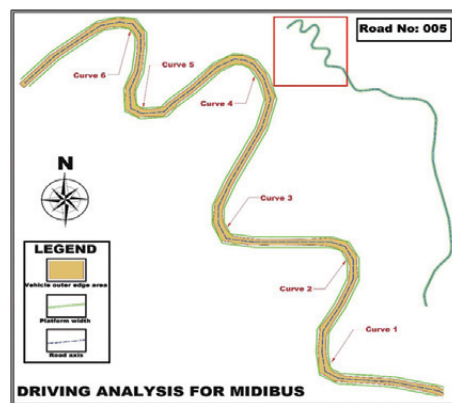


Fig. 6. Results of horizontal driving analysis for midibus

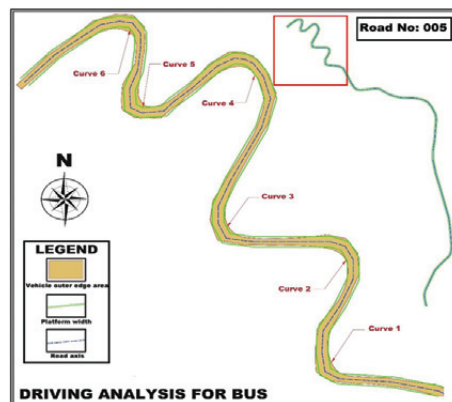


Fig. 7. Results of horizontal driving analysis for bus

According to the results of horizontal driving analysis made for the bus (Fig. 7), it was calculated that total road platform area required for safe driving and maneuverability depending on technical specifications defined in vehicle library was 4124 m². Although such calculated road platform area is smaller than the available road platform area, maximum expansion distance for the bus is 2.28 m for the right platform and 1.62 m for the left platform as seen in Table 5. Total platform expansion requirements in curves are: 74.74 m² on the left platform and 73.73 m² on the right platform.

3.2. Recreational vehicle maneuverability

According to the technical specifications of the automobile, maximum right and left turning angle of the wheel is 31.943°. According to the results of driving analysis graphical report depending on geometrical specifications of the available road, maximum left turning angle of automobile wheel was calculated as 52.764°, while maximum right

turning angle was calculated as 65.694°. According to the results of driving analyses, it was calculated that minimum curve radius required for safe driving quality was 5.103 m, and that maximum turning angle calculated for such value was 31.943° according to the technical specifications of the automobile. It was determined according to geometrical standards of selected road that minimum curve radius in left curves was 3.391 m while minimum curve radius in right curves was 2.963 m; and it was calculated that the maximum necessary turning angle for turning right was 65.693° (Table 6, Fig. 8). As a result of driving analysis, it was found that the current condition of the forest road reduced vehicle maneuverability as maximum Wheel turning angle value (31.943°) calculated according to technical specifications of the vehicle was lower than the maximum wheel turning angle (65.693°) calculated according to geometrical characteristics of the road.

According to the technical specifications of the midibus, maximum right and left turning angle of the wheel is

Table 4. Amounts of expansion required in curves for midibus as a result of driving analysis

Curve No.	Distance from start, km	Curve radius, m	Platform expansion amount, m ²		Maximum platform expansion distance, m	
			Left platform	Right platform	Left platform	Right platform
1	1+025	12.0	-	0.13	-	0.23
2	1+075	12.5	-	-	-	-
3	1+126	15.0	-	-	-	-
4	1+196	13.0	-	-	-	-
5	1+251	10.0	-	0.53	-	0.53
6	1+289	11.0	0.13	0.20	0.23	0.10

Table 5. Amounts of expansion required in curves for bus as a result of driving analysis

Curve No.	Distance from start, km	Curve radius, m	Platform expansion amount, m ²		Maximum platform expansion distance, m	
			Left platform	Right platform	Left platform	Right platform
1	1+025	12.0	10.35	8.00	1.30	1.50
2	1+075	12.5	8.65	10.95	1.20	1.00
3	1+126	15.0	11.01	9.94	1.08	1.19
4	1+196	13.0	11.25	12.80	1.44	1.01
5	1+251	10.0	19.94	16.05	1.10	2.28
6	1+289	11.0	13.54	15.99	1.62	1.10

Table 6. Driving analysis report results showing wheel turning angles used by vehicles on the road and minimum/maximum curve radius

Specifications	Automobile	Midibus	Bus
Left wheel-turns (max)	31.943	42.678	39.660
Right wheel turns (max)	-31.943	-42.678	-39.660
Calculated max wheel turning angle in left direction, degree	52.764	55.331	62.782
Minimal radius for the left curve, m	3.391	4.110	6.522
Calculated max wheel turning angle in right direction, degree	65.693	69.013	79.847
Minimal radius for the right curve, m	2.963	3.620	5.892
Maximal allowed turning angle, degree	31.943	42.678	39.660
Minimal allowed curve radius, m	5.103	4.986	9.088

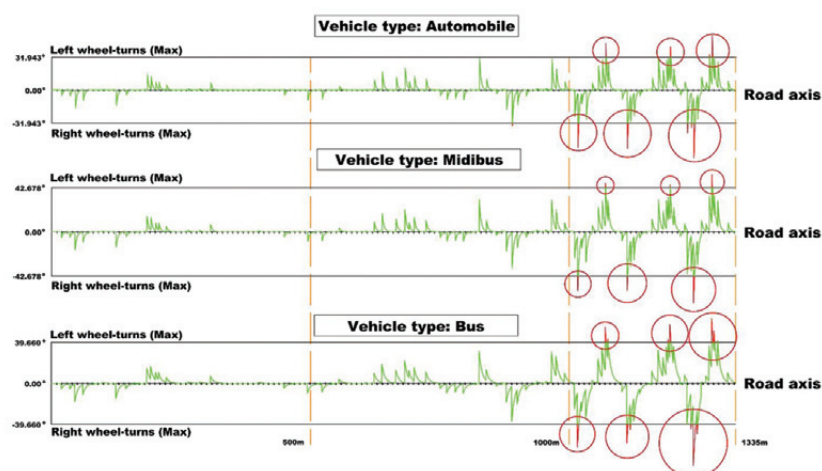


Fig. 8. Graphical report pertaining to wheel turning angles for different vehicle types

42.678°. According to the results of driving analysis graphical report depending on geometrical specifications of the available road, maximum left turning angle of automobile wheel was calculated as 55.331°, while maximum right turning angle was calculated as 69.013°. According to the results of driving analyses, it was calculated that minimum curve radius required for safe driving quality was 4.986 m, and that maximum turning angle calculated for such value was 42.678° according to the technical specifications of the automobile. It was determined according to geometrical standards of selected road that minimum curve radius in left curves was 4.110 m, while minimum curve radius in right curves was 3.620 m; and it was calculated that the maximum necessary turning angle for turning right was 69.013° (Table 6, Fig. 8). As a result of driving analysis, it was found that the current condition of the forest road reduced vehicle maneuverability as maximum wheel turning angle value (24.678°) calculated according to technical specifications of the vehicle was lower than the maximum wheel turning angle (69.013°) calculated according to geometrical characteristics of the road.

According to the technical specifications of the bus, maximum right and left turning angle of the wheel is 39.660°. According to the results of driving analysis graphical report depending on geometrical specifications of the available road, maximum left turning angle of automobile wheel was calculated as 62.782°, while maximum right turning angle was calculated as 79.847°. According to the results of driving analyses, it was calculated that minimum curve radius required for safe driving quality was 9.088 m, and that maximum turning angle calculated for such value was 39.660° according to the technical specifications of the automobile. It was determined according to geometrical standards of selected road that minimum curve radius in left curves was 6.522 m, while minimum curve radius in right curves was 5.892 m; and it was calculated that the maximum necessary turning angle for turning right was 79.847° (Table 6, Fig. 8). As a result of driving analysis, it was found that the current condition of the forest road reduced vehicle maneuverability as maximum wheel turning

angle value (39.660°) calculated according to technical specifications of the vehicle was lower than the maximum wheel turning angle (79.847°) calculated according to geometrical characteristics of the road.

4. Discussion and conclusion

During the study, the forest road with 4 m platform width, primarily used by vehicles intended for management and protection, within Istanbul University Education and Research Forest, was analyzed. Availability and requirements of geometric standards of the road, in case the road No. 005 having a length of 1335 m would be opened to the use of recreational vehicles, were analyzed by horizontal driving analysis in Plateia 2013 Autopath module.

Praticò and Giunta (2014) demonstrate that horizontal geometrical features of road are relevant to safety analysis methods. It was observed that results obtained from driving analysis method, which was exercised for the first time on forest roads, could be used effectively at the stage of planning forest roads or during utilization of different vehicle types on available forest roads. Akay (2003) worked on minimizing total cost of construction, maintenance, and transportation cost with computer-aided forest road design but this study has not driving analysis results and vehicle maneuverability. Akay *et al.* (2004) used the high-resolution digital elevation model for computer-aided forest road design. Abdi *et al.* (2009), Altunel (2006) and Rogers (2005) studied the integration of geographic information system of forestry practices and forest road planning. Gumus (2003) studied the computer-aided forest road network planning and these studies were intended for the design and planning of new and existing forest roads. Karacay (2001) stated that statistical analysis of unstable vehicle driving characteristics and Aruga *et al.* (2005) worked on heuristic planning techniques applied to forest road profiles. Akgul *et al.* (2012) obtained a different results of forest road planning with dynamic CAD programs planning of forest roads. In this sense, our study and results are new and different for above mentioned studies. Forest road planning as a time-consuming and

complicated process both because it requires environment-friendly road building, and due to the requirement to observe economic costs. As a consequence, it is considered that the results of this study comprise a significant indicator in respect of optimum vehicle selection and cost problems that might be encountered during this complicated decision-making process in case of improvement of geometrical standards of roads, driving analysis performed by Plateia 2013 software and, in addition, ability of all kinds of vehicles to be driven safely and comfortably on forest roads.

Acknowledgements

This study was supported by the Scientific and Technological Research Council of Turkey (TUBITAK) (Project No. 113O975)

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Received 2 September 2014; accepted 7 January 2016